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GEOLOGIC-SEISMIC STUDY

PHASE I

FOR THE
CITY OF NEWPORT BEACH
GENERAL PLAN

WOODWARD-McNEILL & ASSOCIATES
CONSULTING ENGINEERS & GEOLOGISTS

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PHASE I
GEOLOGIC/SEISMIC STUDY FOR THE CITY OF NEWPORT BEACH GENERAL PLAN

for

City of Newport Beach
3300 Newport Boulevard
Newport Beach, California

by

WOODWARD-McNEILL & ASSOCIATES
Consulting Engineers and Geologists

Orange
30 October 1972

Mayor and Members of the City Council
City of Newport Beach
3300 Newport Boulevard
Newport Beach, California

SUBJECT: PHASE I - GEOLOGIC/SEISMIC STUDY FOR THE CITY OF NEWPORT BEACH GENERAL PLAN

Gentlemen:

In accordance with your authorization, we have completed the first phase of the Geologic/Seismic Study for the City of Newport Beach. The results of that study are included in the attached draft report.

We would be happy to meet with you after you have reviewed the report to answer any questions or discuss plans for further study. Please contact one of the undersigned at your convenience.

Yours very truly,

WOODWARD-McNEILL & ASSOCIATES

By Hans Ewoldsen
Hans M. Ewoldsen

By Steven C. Haley
Steven C. Haley

By R L McNeill
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1.0 INTRODUCTION

The rapid urbanization of Orange County is placing ever increasing demands on the natural resources of the County, and in particular on those resources along the prime coastal strip. The projected corporate bounds of the City of Newport Beach comprise a major portion of that coastal strip. The increased emphasis on effective maximal utilization of remaining open and redevelopable space requires that the land-use planner use all available information in the formulation of a General Plan, not only to fit future development to the area, but also to provide for the public well-being. Although urban geology is but one item in the bank upon which the planner must draw, it is nevertheless a critically important item which impacts on many of the elements of the General Plan.

While urban geology has only recently been recognized as having appreciable bearing on the growth and/or maximal use of a city's natural resources, its principles are relatively well known. When correctly applied, urban geology may aid the planner to make most effective use of the resources available, avoid

troublesome geologic problem areas, and increase the public safety.

1.1 PURPOSE

The purpose of this geologic/seismic study is to provide the City of Newport Beach with the necessary data and data interpretation to take the maximum advantage, in terms of development and safety, of the city's natural geologic setting.

1.2 SCOPE

This Phase I Geologic/Seismic Study Report presents the City of Newport Beach with land planning data and recommended planning guidelines for the Study Area indicated in Fig. 1. The land planning influences of the following geologic/soils/seismic subject areas are included:

1. Geologic setting
2. Location of major faults
3. Seismicity
4. Seismic hazards
5. Tsunami
6. Slope stability
7. Expansive/collapsible soils
8. Erosion
9. Shoreline regression
10. Land subsidence
11. Mineral resource depletion, and
12. Flooding

Although outside of the geologic/soils/seismic study field, a brief review of the potential flood hazard has been included at the request of the city.

The wide study scope and budget limitations have necessarily limited the depth of the study. The methods used to accumulate data and the limitations to the study are discussed below. Recommendations for continuing Phase II studies are presented in Section 4.0.

1.3 METHODS OF DATA ACCUMULATION

No site investigations or laboratory testing were made for this s4udy. All of the data used for this study are from the following sources:

1. Soil and geologic reports in the files of the City of Newport Beach, the Irvine Company, and Woodward-McNeill and Associates,
2. Published papers,
3. Interviews, and
4. Woodward-McNeill and Associates' experience in the Southern California area.

A listing of the majority of the sources of information identified in Items 1, 2 and 3 above are presented in Appendix G, "Bibliography and References".

1.4 LIMITATIONS

Land planning must be a dynamic process, or it becomes dated and obsolete. The same is true for the background data used to make land planning decisions. It is, therefore, intended that information presented in this report be updated as

additional data become available. This is especially true in the field of seismicity and soil dynamics where the state of knowledge is expanding rapidly.

It has been attempted within the body of the report to point out limitations in data and areas where additional study is necessary. The report is concluded with recommendations for further study.

2.0 GEOLOGIC SETTING

The City of Newport Beach lies on and adjacent to a natural harbor on the Orange County coastline (Fig.1). It is bounded on the north by the Santa Ana River, on the east by terrace and floodplain deposits, and on the south by the San Joaquin Hills. The city itself is partly situated on recent marine sands and silts resulting from littoral drift downcoast of the Santa Ana River, and partly on Quaternary marine terrace deposits which border the ocean and Newport Bay (Fig 1A). Development is quite intensive in the Lower Newport Bay area and along the bluffs bordering the Lower Bay. Less extensive, though continuing, development is taking place along the older marine terraces bordering the Upper Bay, and along the Upper Bay itself. Corona del Mar, a suburb of Newport Beach, lies on marine terrace deposits to the south of the main portion of town. These terrace deposits continue south and along the highway to Laguna Beach. Residential development is slowly pushing into the San Joaquin Hills, a faulted, complex mixture of sedimentary and volcanic rocks.

Physiographically, the Newport Beach Study area may be divided into three zones: the harbor and estuarine zone, including the Upper and Lower Bays and the shoreline beaches; the recent marine terraces, including the bluff areas, Newport Center, and Corona del Mar; and the hill areas, primarily the San Joaquin Hills. Structurally, the study area is underlain by a broad anticlinal structure to the east of the harbor area, aligned in a general N-S direction.

2.1 GEOLOGIC UNITS

A number of geologic units are found within the boundaries of the city. These units are:

Topanga Formation: (Middle Miocene)
The Topanga Formation consists of a buff - colored, medium - to coarse - grained sandstone, which may locally contain tuffaceous volcanic material. It is found along the foot of the bluffs near University Drive, and in the San Joaquin Hills. It is moderately well cemented and massive in appearance.

Monterey Shale: (Miocene Age)

The Monterey Formation is found at the foot of the bluffs along the Coast Highway, along the Corona del Mar and Upper Bay shorelines, and in the San Joaquin Hills. The Monterey Shale is typically a thin - bedded, diatomaceous, silty to sandy shale with siltstone, sandstone and chert interbeds. It is light tan to whitish in color and is commonly contorted and folded.

Capistrano Siltstone: (Miocene-Pliocene Age)

The Capistrano Formation is younger than the Monterey and overlies it. Its appearance is quite similar to the Monterey. The Capistrano is found along the margins of the Upper Bay and in the San Joaquin Hills. It is typically a moderately massive siltstone with clay and sand lenses. Folding and disturbance of the beds is much less than that of the Monterey Formation.

Un-named Sandstone:

The Un-named Sandstone is found along the margins of the Upper Bay. It is light brown to white in color and is poorly cemented. Of relatively minor extent, it is important only insofar as it affects the stability of the Upper Bay bluffs.

Marine Terrace Deposits: (Plio-Pleistocene Age)

The marine terrace deposits comprise the greatest areal extent of surficial geologic units within the city. These deposits form the mesas on which Newport Heights, all the development around the Upper Bay, Newport Center, and Corona del Mar are built. Further older terrace deposits are found at higher elevations in the San Joaquin Hills. These terrace deposits are typically fine - to medium - grained sands with minor amounts of gravel and cobbles.

Estaurine and Lagoonal Deposits: (Recent)

These recently deposited materials are found in the Upper Bay, and to a lesser extent in the Lower Bay, and at the Santa Ana River mouth. They include sands, silts, and clays, with the fine - grained sediments predominating. They have resulted from deposition in brackish water areas. The fine - grained sediments are commonly soft, compressible, and may contain appreciable organic material.

Marine Sands: (Recent)

Most of the Lower Bay development has been built on marine beach sands, either natural deposits or reworked dredged sands. These deposits result from the southward drift of sands carried to the ocean by the Santa Ana and San Gabriel Rivers. The sands are commonly medium grained, and may contain lenses of silt, gravel or organic materials.

3.0 GEOTECHNICAL INFLUENCE ON LAND PLANNING

3.1 SEISMICITY

3.1.1 Non-Technical Summary

This section of the report is prepared to provide information regarding Seismic Hazard for background to the Land Planning Study for the City of Newport Beach. This presentation includes technical material requiring technical education and experience to assimilate. Such a technical presentation is obviously necessary so that the staff of the City of Newport Beach will have the basic data on potential Seismic Hazard within the boundaries of the study area. It is equally obvious, however, that there are many nontechnical people who have intense interest in the findings of this study. For the convenience of those parties, this subsection of the report will present, in narrative form, a nontechnical summary of the work reported herein. Further, a basic nontechnical narrative is included in Appendix C on Earthquake Associated Damage.

Three primary seismic hazards are present within the study area. These hazards are:

1. Ground breakage resulting from a surface rupture of a fault
2. Ground shaking during an earthquake, and
3. Ground failure in the form of soil strength loss which is usually reflected in large settlements, building foundation failures and slope failures.

Such seismic hazards are present in many other areas along most of the Pacific Coast of North and South America, and many other areas throughout the world.

In order to provide the City with preliminary guidelines for land planning purposes, a Seismic Hazard Zoning Map (Fig. 2B) has been prepared. As discussed in more detail in the sections which follow, that map delineates the study areas where these potential seismic hazards should be evaluated.

The study of the effects of 09 February 1971 San Fernando earthquake showed that structures were subjected to ground motions larger than those conventionally stated by the codified building design pocedures in this state, although not necssarily more than expected in other locations in Southern California. For example, present building codes require that multistory structures be designed for accelerations of perhaps 10% of gravity or less, the applicable values being calculated from equations and tables compiled in the building code. Within the City of San Fernando, peak ground accelerations on the order of 30% to 50% of gravity probably occurred on the morning of 09 February 1971. The disparity between these values does not mean that code values ought to be arbitrarily increased. Instead, many procedures must be upgraded based on the lessons learned. Many governmental agencies are presently moving to establish procedures similar to those presented in this report.

The study area has been divided into four ground shaking zones where, because of similar location and geotechnical conditions, structures with certain characteristics

would be expected to react (shake) similarly to the same earthquake. This similar shaking can be evaluated by a Structural Engineer based on the graphs presented as Figs. 2D and 2E.

The Seismic Hazard Zoning Map (Fig. 2B), combined with the information on Table II (Seismic Hazard Requirements), will provide the building official information to evaluate the levels of earthquake consideration required for various types of structures according to their proposed location within the study area. It is not intended to eliminate certain types of structures from various areas through zoning, but instead to set the requirements for the level of earthquake consideration required prior to design and construction. The level of consideration will vary according to the type of structure contemplated. For example, light residential structures to be constructed on flat ground would likely not need any additional consideration over what is conventionally required, but the Seismic Hazard Zoning Map would provide information to the developer and potential owners where the risk may be high for future ground breakage. For the design of critical structures which must be able to function after a large earthquake, however, stringent requirements for earthquake consideration and design should be levied as discussed in Sections 3.1.5 and 3.1.6. Requirements for earthquake consideration and design of structures intermediate to the two extreme examples cited above should vary according to the size,

occupancy and function of the structure (Sections 3.1.5 and 3.1.6).

3.1.2 Introduction

The historic losses in Southern California due to earthquakes have been small; in fact, much smaller than people in other areas of the world are willing to accept almost routinely from hurricanes, tornadoes, riots, epidemics, or traffic accidents. It is generally agreed, however, that the potential for severe earthquake damage does exist, and that the various jurisdictional authorities should provide security against that potential. This section presents the results of our Seismic Hazard Study and includes two powerful tools for the City of Newport Beach to minimize effects of seismic activity on future development.

> Seismic Hazard Map - which will delineate areas where certain seismic hazards should be considered when building.
>
> Safety Guidelines - provisions for the location, design, and construction of critical structures in the city.

It is intended that these tools should discourage unfavorable site/structure combinations; but should not forbid a type of development if the public is willing to provide for proper design and construction, and if the development is consistent with normal zoning ordinances. There is almost no place that cannot be built upon, provided the proper design and construction procedures are followed. The appropriate procedures depend on the proximity to the fault(s), the

characteristics of the fault(s), the foundation soil or rock upon which the structure rests, the size, framing, and materials of the structure, and the importance of the structure.

For a given site, the effects of the proximity and characteristics of the fault, along with the effects of the foundation soil or rock, can all be combined into one simple engineering chart, called the response spectrum, which describes the hazard of ground shaking. In general, the designer uses that response spectrum to select the proper size, framing, and materials to build an economical structure which will withstand the earthquake motions at a site. It is intended that the spectra presented in this report not be used specifically for design except possibly in certain cass discussed later in the report. Instead, these spectra should be utilized as a guide for the building official to require and evaluate earthquake studies of specific sites within the City of Newport Beach according to the type of proposed development contemplated.

In general, the exact response spectra describing ground shaking are different for different sites and different faults; but for geologically similar sites and characteristically similar faults, the response spectra are usually quite similar, at least for the accuracy necessary to describe regional Seismic Hazard. That is, there are areas of similar response spectra in a given locality. It is therefore possible to subdivide areas believed to be affected only by ground shaking during an earthquake into zones according to their

respective response spectra. The zones are called ground shaking zones.

In a given ground shaking zone it may not be economical to build certain classes of structures. For example, in an area of deep alluvium at great distance from a large earthquake, the ground motions will be low-frequency, high-amplitude rolling. In general, very tall buildings tend to respond by amplifying such motions; thus, such a tall building in that area must be extensively reinforced to be safe. That is, such a structure can safely be constructed, but it will probably cost more than if it were constructed in a more favorable ground shaking zone.

Other potential seismic hazards such as ground breakage and ground failure (liquefaction, slope stability, excessive settlement, etc.) generally result in more serious consequences than ground shaking; however, the ground shaking hazard generally covers a larger area of influence as was evidenced in the 09 February 1971 San Fernando earthquake.

Zones of potential ground breakage and ground failure may be delineated in a similar manner as ground shaking zones. In general where the potential hazard is high for these phenomena, these zones will dominate over the ground shaking zone. The general term Seismic Hazard Zoning has been adopted here to encompass all of these phenomena.

An evaluation of these various seismic hazards is presented below. Their influence on the study area is then presented in terms of seismic hazard zoning.

3.1.3 Background

3.1.3.1 Faulting

Several geologic faults may be found within the city boundaries. Of these, the Pelican Hill and Newport-Inglewood Faults are the most prominent. With the exception of the Newport-Inglewood Fault, there is no record of historical activity on any of the faults. There is report of offset of recent terrace deposits in the Upper Harbor View Hills area, which would indicate recent movement in a geologic sense.

An active fault zone, the Newport-Inglewood Fault Zone passes beneath the Lower Bay. This zone has a general N-S alignment, entering the city boundary in the vicinity of the Coast Highway bridge across the Santa Ana River, continuing beneath Balboa Peninsula, and passing just seaward of Corona del Mar. This faulting has localized petroleum deposits in structural folds and traps. These are being produced in the West Newport Oil Field and are known to continue southward beneath the northern part of the city.

The Newport-Inglewood Fault Zone has been rather extensively studied since 1933, the date of the last major activity in this fault system. The fault zone is generally considered to consist of a series of semi - parallel subsurface breaks, defining a zone of rupture along which tectonic stress relief is apparently taking place. From well log records and deep seismic profiling, it is known that there is considerable offset at depth of materials along the fault plane, and that this offset dies out towards the surface. Physiographic evidence,

such as ancient fault scarps and other linear features, can be found in the Huntington Beach, Long Beach and Dominguez Hills areas, but none are evident in the Newport Beach area. Numerous subsidiary faults are common, evidence for several of these being found in subsurface groundwater barriers in the Santa Ana gap. Seismic profiles carried out at sea confirm extension of the Newport-Inglewood Fault Zone to at least the vicinity of Laguna Beach. Further southward extension is unknown at this time. The fault extends northward through Inglewood, apparently ending at the Santa Monica Mountains.

3.1.3.2 Seismic Activities

A recent unpublished open-file report by the California Division of Mines and Geology (62) provides an excellent summary of the seismic activity on this fault system. A listing of the stronger seismic events along this zone between March 1933 and 1970 is presented as Appendix E. From this table, it is seen that at least 10 events of Richter Magnitude 4.0 or greater have occurred during this thirty-seven year period. These events have been distributed along the fault zone and demonstrate the activity of this system. Other significant events occurring prior to the advent of modern strong-motion recording instruments (1933), and directly attributable to the Newport-Inglewood Zone would include earthquakes in 1920, 1927 and 1933. Those occurring in 1920 and 1927 were likely in the magnitude 4 to 5 range, while the 1933 event has been assigned a magnitude of 6.3. A table of historic earthquakes which may have occurred on the Newport-Inglewood Zone

is included as Appendix F. From historic accounts, it appears that the 1769 and 1812 events may have occurred on the Newport-Inglewood Fault and probably had an intensity in the Newport Beach area equal to or greater than the 1933 event, while the 1855 and 1878 events were probably equal to or slightly less than the 1933 event. In any case, the historic and recorded seismicity indicates that recurrence of the 1933 event should be anticipated.

The 1933 Magnitude 6.3 earthquake has been reasonably well documented, and provides valuable information regarding the types and extent of seismic phenomena which were experienced. These descriptions may be used as an indication of similar phenomena which might be experienced during a seismic event which results in similar ground motions in the Newport Beach area.

It should be noted that at the time of the earthquake, most of the construction in Newport Beach was single - family, wood - frame dwellings, many of which have the ability to sustain appreciable motions without severe distress. Further, many seismic phenomena were relatively unknown in 1933, so that the absence of descriptions of these phenomena should not be taken to mean that they did not occur. The epicenter of the 1933 event has been assigned a location some three miles offshore of Newport Beach, at a depth of 10 kilometers. The strong ground motion persisted for approximately 15 seconds, and has been described as a "hard shaking". The earthquake produced major damage in Long Beach, and has hence been labeled the "Long Beach"

earthquake. Major damage to buildings was also sustained in Santa Ana, Garden Grove, and at various locations in the beach areas between Newport and Long Beach. There were at least 78 aftershocks of Magnitude 3.9 or greater in the months following the earthquake. No surface fault displacement was recorded, indicating that the movement was confined to the deeper portions of the fault plane, or occurred on an offshore fault trace.

With respect to surface effects of the earthquake, "mud volcanoes" appeared at Cabrillo Beach and Seal Beach; "water was ejected from cracks" in the flood plain deposits between Huntington Beach and Newport Beach; pavement offset, lateral spreading, and settlement at bridge abutments occurred along the Coast Highway; in Newport Beach the water mains leaked and slides occurred along the bluffs near Balboa Island; and cracks appeared in the highway between Newport Beach and Laguna Beach. These phenomena are indicative of strong ground shaking and, more importantly, of at least partial soil liquefaction.

3.1.3.3 Generalized Soil/Geologic Profiles

As is evident from the foregoing discussions, the study area encompasses a wide range of geologic conditions. The soil and bedrock conditions were evaluated from the sources indicated in Section 1.3, above. Based on the variations in soil and groundwater conditions and depth to bedrock, the study area has been divided into four Ground Shaking Zones, each with its own generalized soil/geologic profile. The

shaking zones are indicated in Fig. 2B and the profiles are presented on Fig. A-1, Appendix A.

To divide such a geologically complex area into only four generalized profiles is a major simplification, necessitated by the constraints of the study. Certain areas, especially portions of zones 3 and 4, are not typical of those profiles. Such conditions should be studied more thoroughly as discussed in Section 3.1.5, below.

3.1.4 Analyses

3.1.4.1 Rock Motions

The study area has, in the geologic past, been subjected to seismic ground motions from activity on numerous source faults. In an effort to estimate the reasonably severe conditions of ground shaking which might be experienced at the site due to movement on the nearby or distant faults, the potential magnitude of activity on each causative fault, and its effect at the study area were studied. Of the known faults, three were postulated as being potential generators of significant earthquake motions at the site. These postulated controlling, causative faults, which are shown on Fig. 2A, are the

Newport-Inglewood Fault
Whittier-Elsinore Fault
San Andreas Fault

Recent studies by Seed and Idriss (24) have compiled empirical geophysical data on earthquake effects into simple but approximate forms which may be used to supplement recorded data in estimating potential earthquake

magnitude, and to allow the estimation of ranges of engineering characteristics of earthquakes in bedrock materials. The engineering characteristics of most use are the maximum accelerations and predominant periods of the time-histories which might result in the bedrock under a given site as a result of movements along a certain fault. Those characteristics, acceleration and period, depend on the magnitude of the earthquake and its distance from the site.

Earthquake characteristics are presented in Table I. Those characteristics were estimated from the above procedures, combined with the guidelines indicated below:

(a) The length of the fault was determined from the California Division of Mines and Geology, Geology Map of California (1:250,000).

(b) Fault rupture was assumed over one-half the length of the fault.

(c) Fault rupture was assumed to progress along the fault at a velocity of 2 miles per second.

The earthquake parameters presented in Table I represent our estimate of the credible maximum earthquake event which could occur on each fault.

TABLE 1

EARTHQUAKE PARAMETERS

EARTHQUAKE DESIGNATION AND DESCRIPTION	POSTULATED CONTROLLING CAUSATIVE FAULT	DISTANCE TO CITY OF NEWPORT BEACH (MILES)	LENGTH FAULT(S) (MILES)	ESTIMATED MAX. PROBABLE RICHTER MAGNITUDE	ESTIMATE PERIOD AT SITE	ESTIMATED MAX. BEDROCK ACCELERATION AT THE SITE (g)	ANTICIPATED DURATION (sec)
A. Close Moderate magnitude earthquake (strike slip)	Newport-Inglewood	< 5	50	7.0	0.35	0.24	25
B. Local moderate to high magnitude earthquake (strike-slip)	Whittier-Elsinore	24	120	7.6	0.35	0.18	60
C. Distant high magnitude earthquake (strike-slip)	San Andreas	60	>200	8.4	0.55	0.12	100

3.1.4.2 Soil Motions

To determine soil and ground surface motions, the generalized soil profiles shown on Fig A-1 (Appendix A) were modeled into analytical lumped-mass systems with springs representing soil stiffness and dash-pots representing soil damping. Existing earthquake acceleration time-history traces were modified to the acceleration-period characteristics indicated in Table I. The resulting traces for the Newport-Inglewood and Whittier-Elsinore events were similar, and were combined into one event named the Newport/Elsinore event for this study. Both modified earthquake traces (representing the San Andreas and Newport/Elsinore events) were input at the bottom of the lumped-mass analytical models of all four profiles. The resulting ground - surface soil responses are presented in the form of response spectra on Figs. A-2 through A-5 (Appendix A) for both earthquake events for each of the four soil profiles. Enveloping spectra are also shown.

3.1.4.3 Structural Response

The response spectra and envelopes have a somewhat irregular shape, and their peaks and valleys represent a degree of refinement which is beyond the accuracy of the present study. For these reasons the enevlopes should be smoothed. This smoothing process includes consideration of repetition of high acceleration pulses to evaluate the severity of the response spectrum peaks, thereby reducing such peaks if they are controlled by but one or two high acceleration pulses.

The response spectrum envelope for Ground Shaking Zone 1 (Fig. A2) is similar to the envelope for the response spectrum for Ground Shaking Zone 4 (Fig. A5). Likewise, the response spectrum envelopes for Zones 2 and 3 are similar. One suggested Survivability Spectrum (Section 3.1.4) for Ground Shaking Zones 1 and 4 and one for Zones 2 and 3 are presented in Fig. 2C. Also shown on Fig. 2C is the proposed Basic Design Spectrum (for 5% structural damping) proposed by the City of Los Angeles (40).

Response spectra represent the estimated response (acceleration, velocity and displacement) for a single degree of freedom system of any particular natural period of vibration. They may be used to estimate the earthquake response of structures idealized to single degree of freedom systems. The response spectra presented in Figs. A-2 through A-5 (Appendix A) are calculated for 5% structural damping.

The structural damping, together with the period, define the structure, but they are not indicative of the amount of ductility, and consequent maintenance, which might be appropriate. The planning for structures should contemplate the ductility of the structure (controlled by framing and building materials, and the amount of maintenance). The ductility can be described by a ductility factor which is equal to the ratio of the dynamic deflection for which the structure is designed to that deflection at the working stresses. This ratio will vary with building materials and framing, as well as with the level of maintenance which might be

acceptable after the earthquake. This last item involves an element of risk, and, depending on how critical the structure is, large or small amounts of maintenance might be acceptable. This aspect of risk will be discussed further in Section 3.1.6 below (Critical Facilities).

Based on the foregoing definition of ductility, families of response spectra for various ductility factors can be drawn for each soil profile. Such families of spectra are drawn for profiles 1 and 4 (Ground Shaking Zone 1 & 4) on Fig 2D and profiles 2 and 3 on Fig 2E. The use of these curves for assessing Seismic Hazard will be discussed in Section 3.1.5 and 3.1.6.

3.1.4.4 Liquefaction

The term liquefaction as used here is the phenomenon in which generally cohesionless soils become fluid (lose all strength) during an earthquake. This phenomenon falls in the ground-failure category for planning purposes. Liquefaction results from vibration of sands and silts which are saturated (usually below the groundwater table). During vibration the sands tend to compact and thereby increase the pressure in the water between the grains. The pressure causes the water to move. When the soil becomes fluid it also becomes mobile. Liquefaction can result in surface movements from inches to tens of feet.

Studies of recent earthquakes have concluded that some liquefaction has occurred in every major earthquake observed around the world in the past 10 to 15 years.

Other studies have concluded that liquefaction has been associated with major earthquakes throughout history. Some recent examples of liquefaction include:

(a) Niigata (10 June 1964, M7.3) - Extensive liquefaction to low lying port city adjacent to the Sea of Japan. Some of the most dramatic results were 5 story apartment buildings listing to as much as an 80° angle.

(b) Alaska (1964,M8.4) - Loss of port facilities at the cities of Seward and Valdez due to liquefaction - induced flow slides.

(c) San Fernando (9 Feb.1971, M6.5) - Liquefaction at both Upper and Lower Van Norman Dams, the Jensen Filtration Plant and Juvenile Hall.

To have a potential for liquefaction, three conditions are necessary.

(a) Generally cohesionless soils.

(b) Groundwater.

(c) Moderate or major earthquake.

In Newport Beach, as in many other areas along most of the Pacific Coast of North and South America, and many other areas

throughtout the world, all these conditions exist. For liquefaction to occur under these conditions, it is necessary for the shear stresses caused by the earthquake at the zone of liquefaction to exceed the liquefaction strength of the soil. Thus, larger earthquakes are required to cause liquefaction at a site for denser soils, or for more distant events.

We have analyzed the liquefaction potential in the study area by the method outlined by Seed and Idriss (25). The shear stresses for each profile caused by the earthquake parameters, indicated in Table I, were taken from the output of our lumped-mass computer program. Our preliminary studies indicate that liquefaction could occur in portions of the study areas as described in Section 3.1.5.3, below, as a result of a major earthquake on the San Andreas Fault or a moderate earthquake on other faults including the Newport-Inglewood or Whittier-Elsinore fault systems.

3.1.5 Seismic Hazard Zoning

The concept of Seismic Hazard Zoning is relatively new, but it depends only on modern accepted geologic and engineering methods. Consideration of the Seismic Hazard Zoning concept will lead to safer development, letting contemporary economics and usual zoning ordinances determine, in a natural way, the type of structure which will be built. We believe that this approach far surpasses any restricted building approach which would have an artificial but stifling effect on growth and development.

A preliminary Seismic Hazard Zoning Map is presented as Fig. 2B.

3.1.5.1 Ground Breakage

The technique of delineating the Seismic Hazard of ground breakage into zones for the limited level of effort intended here has been greatly simplified. The simplification involves taking published data on mapped faults and ground breakage such as that shown on Fig.1 and enveloping fault zones and each fault trace with a 1000-ft. wide zone of potential ground breakage as is done on the Seismic Hazard Map, Fig. 2-B. The choice of a 1000-ft. wide zone is, in our opinion, sufficient to encompass not only the presently mapped faults or zones of ground breakage, but also most subsidiary unmapped zones of older unmapped breakage. The 1000 ft. zone is intended only for broad planning purposes; and it should not be interpreted literally or used for designs.

3.1.5.2 Ground Shaking

The effects of ground shaking more than any other Seismic Hazards are controlled by the type of structure for any given level of intensity of shaking. For this reason, response spectra are utilized here to describe ground shaking. The methodology of response spectrum determination is shown graphically in Appendix A. The specific determinations made for the present study were presented in Section 3.1.4. Four Ground Shaking Zones are indicated on Fig. 2B. Each zone is

associated with a soil/geologic profile (Fig. A-1, Appendix A) and a family of response spectra (Figs. 2D and 2E).

3.1.5.3 Ground Failure

Ground failure during an earthquake is usually manifested in the forms of excessive settlement, liquefaction (Section 3.1.4.4), or slope instability (Section 3.3). Excessive soil compaction settlement occurs in loose, granular soils. In general, for the study area, such soils are saturated; and therefore, soil compaction, if it occurs, is expected generally to be associated with liquefaction.

Our studies indicate that the areas of potential liquefaction include much of Ground Shaking Zone 3 and Ground Shaking Zone 4 (Fig. 2B). Liquefaction is not considered as a major Seismic Hazard in Ground Shaking Zones 1 or 2. Until more detailed studies are completed, we recommend that Ground Shaking Zones 3 and 4 be considered zones of potential ground failure due to liquefaction; but this preliminary conclusion should be checked before firm planning is based on it.

Slope instability (Section 3.3) is also a potential Seismic Hazard. We have zoned those portions of the study area where two conditions both occur; the present ground slope is about 25 percent or steeper, and less stable geologic formations are exposed. Ensuing natural slopes in the study area are not generally suspected to fail due to the earthquake process alone. However, earthquakes could trigger slides in the slope instability seismic hazard areas where other

failures such as undercutting and heavy rains have reduced stability.

All of the zones of potential ground failure are presented on the Seismic Hazard Zoning Map, Fig. 2B.

3.1.5.4 Use of Seismic Hazard Zoning Map

Recommended ground breakage, ground failure and ground shaking zoning are presented on Fig. 2B, Seismic Hazard Zoning Map. The zones of potential ground breakage should be considered separate zones not controlled by ground shaking. The ground shaking zones 1,2,3 and 4 correspond with the generalized Soil/Geologic Profiles, Fig. A-1. The families of response spectra for zones 1,2,3 and 4 may be used only for preliminary ground shaking and liquefaction evaluation.

Fig. 2C presents recommended survivability spectra based on the maximum credible earthquake events which could occur. The Building Official may or may not wish to use such spectra for preliminary design spectra. The Building Official may wish to use a less severe design spectra to design structures for little or no post design earthquake maintenance.

Survivability earthquakes are very severe events, for which damage would be widespread throughout the Los Angeles basin. A structure might be designed to survive without complete collapse for such an event though it would likely require substantial reconstruction and reinforcement in the aftermath (i.e., the spectra from these very large earthquakes could be used for the survivability design of the

structure at high ductilities). It is the responsibility of the building official to determine the ultimate design philosophy compatible with public safety. This firm would be happy to provide assistance for such decision making.

The zoning presented in Fig. 2B should be used in conjunction with recommendations in Table II and the discussion in Section 3 of this report. The overlap in ground shaking zoning in some areas represents uncertainty as to which soil/geologic profile is most closely represented by any of the idealized soil/geologic profiles. In areas where Ground Shaking Zones overlap, the Ground Shaking Zone which results in the most severe conditions should be used. The zoning limits must be considered approximate both in soil/geologic conditions and in areal extent, and not necessarily representative of any one particular site.

The Seismic Hazard Map and the response spectra are intended predominately for identifying seismic hazard on a regional basis, not for use in structural design. As an example, we propose to group structures into three broad categories and describe example use by the Building Official. The following categorization of structures is suggested: (1) residential and 1- to 3-story light industrial or commercial structures; (2) medium rise or high-density occupancy, noncritical structures; and (3) high rise or critical structures (hospitals, schools, etc.). The suggested uses of the Seismic Hazard Zoning Map and spectra for these structural categories are presented in Table II. For seismic-hazard consideration, the

TABLE II

SEISMIC HAZARD REQUIREMENTS

STRUCTURE TYPE	GROUND SHAKING ZONES	POTENTIAL GROUND BREAKAGE ZONE	ZONES OF POTENTIAL GROUND FAILURE *
1. Residential and 1- to 3-story light industrial or commercial structures	None	Indicator of risk of potential ground breakage	Indicator of potential risk
2. Medium rise (4-6-stories) high density occupancy or unusual structural geometry	Can be used as a conservative minimum design requirement by structural engineers if no aseismic design investigation is done. If a reduction is desired a special investigation should be performed.	Seismic hazard investigation should be required.	Seismic hazard investigation should be required.
3. High-rise (greater than 6-stories) and critical structures (hospitals, schools, etc.)	Special investigation should be performed for each structure.	Not advisable to site critical structures in this area unless very extensive investigation provides information to the contrary.	Not advisable to site critical structures in this area unless very extensive investigation provides information to the contrary or special designs to account for the potential ground failure are incorporated in design.

* For the study area these areas may be zones of potential liquefaction (i.e., ground shaking zones 3 and 4) or zones of potential seismically triggered slope instability.

builder of a particular structure can evaluate what order of magnitude of a seismic design will be required for a building permit according to the fundamental period of the proposed structure and what ductility (maintenance) he wishes to use. For structures in Category 2, the builder may choose to use the curves on Figs. 2D and 2E, or to perform a specific seismic investigation for that specific site. If the builder elects the first option, he should provide recommendations from a structural engineer for the fundamental period of the structure and ductility factor. Further details on design philosophy for critical structures are described in Section 3.1.6 which follows.

3.1.6 Site Studies for Critical Facilities

Future site studies for hospitals and other emergency critical facilities in the Southern California area must be done more carefully and thoroughly than has been the general standard of practice in the past; The City should require, through its Department of Community Development, a thorough and complete study of the site and building design for all semi-public and private facilities which are of the emergency-critical type. Such buildings or structures would include, but not be limited to:

(a) Hospitals, and other medical facilities having surgery or emergency treatment areas;

(b) Fire and police stations;

(c) Municipal government centers;

(d) Public utility service centers and storage facilities;

(e) Designated civilian emergency centers;

(f) Schools accommodating any grade through the 12th grade.

The above list was obtained from the recent proposed change to the City of Los Angeles proposed building code change.

The thorough studies referred to for the above-listed structures should include but not necessarily be limited to the following considerations:

(a) Adequate geologic mapping, trenching and boring to determine that surface faulting and ground breakage has not occurred on the site, and is unlikely to occur in the future.

(b) Adequate boring and field and laboratory testing to determine accurately the subsurface profile and the static/dynamic properties of the soil/rock materials;

(c) Thorough regional studies of all possible causative faults and fault systems which could generate motions at the site;

(d) Studies to determine the character of ground motions at the site, and to derive response spectra for all important causative faults;

(e) Calculation of design response spectra, based on repetition, and on structural properties (damping, ductility);

(f) Careful dynamic design of a cohesive structure, each element of which works as a part of the entire structural system;

(g) Thorough study of the ways in which the structure might disassemble if it were to fail, and inclusion of redundant backup features to control disassembly so that outright collapse cannot occur.

(h) Design of a damage control plan for emergencies;

(i) Design of anchorage and bracing for all critical in-structure systems (examples: emergency power, heat, light, oxygen supply, etc.), based on factors derived from dynamic analysis, providing generous and conservative safety factors; and the manufactured equipment and appurtenances purchased for such a facility should likewise be designed;

(j) Selection of architectural details and fixtures that aid structural response and will not be hazardous;

(k) Planning and policing of inside space use so that rolling or sliding furniture and

fixtures will not be hazardous, and so that caustic or critical chemicals will remain intact;

(l) Thorough inspection of construction to ensure that designs are complied with, to include a written certification by the Contractor that all work was done in strict accordance with the plans and specifications;

(m) Periodic inspection of all structures and systems to determine that to detrimental modifications are made, and that proper maintenance is provided.

The foregoing tabulation is intended as a check list for the building official in evaluating the level of seismic investigation for critical structures.

3.2 TSUNAMI

A tsunami is a sea wave generated by a submarine earthquake, landslide or volcanic action. A major tsunami from either of the latter two events is considered to be extremely remote for the study area.

Submarine earthquakes are common around the edges of the Pacific Ocean, as well as other areas. Therefore, all of the Pacific Coastal areas are subject to this potential hazard to a greater or lesser degree.

Tsunamis travel across the ocean as powerful, long, but low waves; perhaps 50 miles long and only 1 or 2 feet high(19). Traveling at almost 500 mph in the Pacific, such a wave in the open causes no problems, and, in fact, the slope of the wave front may be imperceptible to a ship at sea. However, as the tsunami waves approach the coast line, they are affected by shallow bottom topography and the configuration of the coast line, which transform the waves into very high, potentially devastating waves. If large waves do not occur, strong currents (as high as 40 feet per second) can cause extensive damage.

The most damaging tsunamis are usually associated with vertical tectonic displacements. Furthermore, observable tsunamis are usually only caused by large earthquakes with a magnitude of about 7.5 (M7.5) or greater (19). Smaller tsunamis are usually only recorded in the form of tides.

A tsunami on the order of 20 ft. in height hit Crescent City, California, in March 1964, as a result of the Magnitude 8 Alaskan earthquake, and resulted in damages of approximately

$11,000,000. Most of the loss was harbor and boat damage. This "run-up" inundated about 30 city blocks in an area of about 100 acres. The majority of one-story, wood-frame buildings that were situated in areas where the water depth exceeded about 4 feet were either destroyed outright or were so badly damaged that they had to be demolished later. This destruction extended over approximately half the area inundated. Losses in the remaining half was due primarily to water damage. Although there was some damage at the Los Angeles ($275,000) and Long Beach ($100,000) harbors associated with the Alaskan earthquake (20), there was no significant damage reported at Newport Beach (E).

Movement along the Newport/Inglewood fault system would be expected to be primarily horizontal, based on present information. The 1933 Long Beach earthquake (M6.3) occurred on the Newport/Inglewood fault system, and did not result in tsunami damage at Newport Beach. It is questionable that movement along the Newport/Inglewood fault system could cause a significant tsunami affecting the study area. Tsunamis can, however, be triggered by distant earthquakes, as in the case of the one which hit Crescent City, about 1500 miles from the triggering movement.

It is not possible to predict the likelihood or magnitude of a major tsunami. The Newport Beach area is afforded some natural protection by Santa Catalina and San Clemente Islands. This firm is not familiar with any tsunami damage which has occurred in the study area. It is felt that the chance of major damage from a seismic sea wave is not great for the coastal beaches and Newport Bay Harbor entrance, and is negligible for

inland bay areas. Waves can, however, also result from landslides into Newport Bay. For land planning, it is recommended that emergency-critical faciliies (Secton 3.1.6) not be constructed on low-lying waterfront properties.

3.3 SLOPE STABILITY

Figure 3 is presented to denote the areas of steeply sloping terrain (areas where the existing ground slope is on the order of 25% or more, so that major cuts and fills are necessary for development), and areas where the more unstable geologic formations are exposed. These are the areas of most concern in considering slope stability. It is unfortunate that, to a large extent, those areas overlap. The more unstable areas generally represent the exposures of Monterey Shale, the Capistrano Formation and the Trancos Member of the Topanga Formation.

To a large extent, these potentially more unstable areas remain undeveloped. To develop these areas in a stable and economical manner, it will be necessary to evaluate local slope stability conditions carefully, and to reinspect cut slopes during construction. The stability of slopes in these materials depend, not only on the inclincations of the slopes and the properties of the geologic formation, but also on bedding planes, vagrant perched water seepages, and faulting. The city will want to see that the proper geotechnical investigations and planning are employed in developing these areas.

3.4 EXPANSIVE AND COLLAPSIBLE SOIL

An expansive soil is one which will substantially increase in volume when wetted and, because the process is reversible, shrinks when it dries. This is characteristic of cohesive, clayey soils, such as "adobe". Collapsible soils are loosely packed, fine-grained materials which are sometimes lightly cemented with soluble materials or clay. When these materials become wet, the soluble cementation, if present, is destroyed with a resulting collapse of the soil structure. This leads to large settlements even under small loads.

Southern California and, in particular, Orange County, is an area plagued by potentially expansive soils. Not only do direct damage costs amount to many millions of dollars per year (for Southern California), but the damage is usually reflected in lower property value and resulting tax revenues. The problems resulting from potentially expansive soils can be controlled by proper engineering, and by proper construction practices. Therefore, the presence or absence of expansive soils should not be a critical factor in overall land planning. What is critical is to ensure proper engineering and construction practices are observed. The City should remain cognizant of the problem; especially as the city may develop northward and eastward, it would be growing into areas of potentially expansive soils. Figure 4 divides the study area into expansive soil probability zones as identified below:

Expansive Soil Zone I — Moderate to highly expansive soils likely. Developments

	should include plans to account for such conditions.
Expansive Soil Zone II	Moderately to highly expansive soil possible. Site investigations should evaluate such conditions.
Expansive Soil Zone III	Moderately to highly expansive soils are not expected. Site investigations should confirm these conditions.

We recommend that the Department of Community Development review plans for projects in Expansive Soil Areas I and II to see that precautions are being taken in those areas to minimize the problems associated with expansive soils where necessary.

Collapsible soils are not considered prevalent in the study area, and need not be considered in overall land planning. This condition can, however, occur locally, and should be addressed by all geotechnical studies in the City.

3.5 EROSION

Erosion has been a major factor in shaping the Newport Beach land areas. Most of the low-lying land in the Bay area is the result of material eroded upstream and transported by water to its present location. This process continues, especially during periods of flooding, and in doing so reduces river and bay capacity for flow, storage and navigability. On a national scale, the estimated annual cost of damage resulting from sedimentation alone is $500,000,000 (23). These problems are especially acute for the Santa Ana River and Newport Bay and its tributaries.

Although wind erosion is significant in many areas, water is the major source of erosion in the study area. Silts and fine sand, because they are light (unlike heavier sand and gravel particles), are usually not strongly cemented (like clays), and are generally the most susceptible material to erosion. Therefore, it is not surprising that the soils making up the land masses in the Lower Bay area are composed predominantly of silts and fine sands.

While much erosion is attributable to natural causes, civil engineering projects can also have major negative effects. The most common negative effect is to remove the natural plant/tree cover, and to cut into the easily eroded sterile underlying materials. Construction into hillsides results in steep slopes which erode easily and cannot be easily maintained.

Less obvious negative land development effects can include such factors as raising the ground water level which can

dissolve natural soil cementing agents, thus increasing their erodability (21).

It is estimated that erosion on grading projects is 200 times greater than for pasture land and 2000 times greater than for land in timber (23). Many land-planning and construction practices can be used to reduce erosion and sedimentation. These practices include:

(a) Use sites best suited for development. Sites with steeply sloping topography, highly erodable materials, or in natural stream channels can be left as green belt areas. Structures and other facilities can be clustered in areas more favorable to development.

(b) Minimize grading. Fit developments to the existing topography. Leave as many trees and plants in place as possible.

(c) Leave exposed soil bare for as short a time as possible. In developing large tracts, work in small units to minimize exposure time. In some cases, areas can be covered with mulch or planted if they must be left graded but undeveloped for a considerable time.

(d) Control run-off during and after construction. This requires planning erosion controls, such as terraces, drains, berms, storm sewers and channels, prior to the start of grading.

(e) Detain run off on the site. Construct sediment basins on site to prevent loss of materials.

We recommend that for larger projects, especially those where significant earth moving or land clearing is contemplated, or where ground water levels or drainage courses will be effected, the effects of the development be analyzed with regard to the following questions:

(a) What is the susceptibility to erosion of the materials at the site?

(b) What natural mechanisms are working to increase or retard erosion (i.e., slope, planting, topography, etc.)?

(c) What effect will the project have on the existing erosion conditions?

(d) With the presently planned erosion control features, what will be the primary effects of these changes at the site?

(e) What will be the secondary effects of these changes downstream?

(f) If the answers to Questions d and e are unfavorable, what changes can be made in the proposed project to prevent those unfavorable effects.

As an initial guide to the answer to Question a, above, Fig. 5 has been prepared by generalizing tentative erosion classifications presently being confirmed and/or modified by the Soil Conservation Service of the United Stated Department of

Agriculture (C). The erosion classifications indicated in Fig. 5 are defined by the Soil Conservation Service as follows (22):

> Uneroded or slightly eroded: Less than 25 percent of the original surface 6 inches or of the A horizon if deeper, or of the plowed layer removed.
>
> Moderately eroded: 25 to 75 percent of the original surface 6 inches, or the A horizon if deeper, or if the plowed layer is removed. Where eroded by wind, hummocks up to 25 inches high may occur as well as an occasional blowout area.
>
> Severely eroded: 75 percent or more of the original surface 6 inches, or the A horizon if deeper, or if the plowed layer has been removed and as much as 25 percent of the subsoil. Occasional deep gullies and frequent shallow gullies may be present. Where eroded by wind, hummocks more than 25 inches high and blow-out areas are common.

The data presented in Fig. 5 should be updated and modified as more data is obtained.

3.6 SHORELINE REGRESSION

Beach erosion has been a continuing problem in the West Newport Beach area (13). Waves affecting the Newport Beach area vary seasonally, approaching from the south during late spring, summer, and fall, and from both south and west during the winter storm periods. Some shoreline littoral movement also occurs as local westerly winds blow sporadically onshore (E).

The annual preponderance of wave energy originates, however, from surf generated by storms occurring in both the southern hemisphere, and in the northern hemisphere off the Central American coastline, during April through October. As these waves proceed northward, they attack diagonally, and are not adequately refracted to attack the affected West Newport Beach in a frontal fashion. Thus, the major littoral movement is upcoast with an inadequate amount of beach material returning to replace the loss. The net effect created a serious shoreline regression problem in certain areas west of the Newport Pier. East of the Newport Pier (Balboa) the beach front is oriented more towards its prime field of exposure to wave energy,and beach erosion has not been a serious problem within this portion of the study area (13,A,E).

The general beach limits were established in 1936 when 5.5 million cubic yards of sand were dredged from the Newport Bay and placed upon all beaches of the Newport-Balboa ocean front. Although Balboa Beach has held its configuration, the West Newport Beach has had a general loss of beach width. Beach erosion became very serious during the 1965-69 period.

Subsequently, major filling and construction operations have been continuing in that area. About 2 million yards of additional fill have been placed. In addition, four rubble mound rock groins have been constructed, with four more scheduled to be built, to reduce littoral drift. The groins have been effective in reducing beach erosion. One additianal groin is being considered at 62nd Street. However, it is under interim study to determine its actual need. It is expected that, with the addition of the groins, the erosion problems will be better controlled, although the system will still require study and periodic maintenance (E).

In the past, the prime source of beach sand has been local rivers. The Santa Ana River deposited 3 million cubic yards of sand in a delta in front of the Santa Ana River mouth jetties after the heavy rains of the winter of 1968-69. The river only deposits substantial quantities of sand during flooding periods. Other sources of sand have included dredging and import from sand and gravel quarries upstream along the Santa Ana River. These sources, however, require strong quality control measures to avoid transportation of material containing high colloidal content onto the bathing beaches (E).

It does not appear that shoreline regression need be a major factor in overall land planning. The consequences of beach uses should be evaluated on an individual project basis.

3.7 MINERAL RESOURCE DEPLETION

Mineral resource depletion is usually a result of urbanization. Because the process is slow and does not attract attention like a flood or an earthquake, it often goes unnoticed by the public. However, the accumulative depletion costs associated with building over mineral resources, and thus reducing their availability can be quite large.

The primary mineral resource which can be lost by urbanization in the study area is most likely the loss of building materials. Such materials include sand, gravel and crushed rock for concrete and road base and also clay for brick and tile. This study did not indicate any major sources of aggregate in the study area. However, there are nearby sources along the Santa Ana River and on Irvine property. There are sources of granular fill material in the hills east of MacArthur Boulevard.

In order to formulate a plan to minimize mineral resource depletion, it is necessary to evaluate the requirements for such mineral resources in the study area, and to correlate that requirement with the available resources within or adjacent to the study area. In addition to aiding in land planning, such a study might indicate areas which would be of priority to annex into city boundaries.

3.8 SUBSIDENCE AND EXCESSIVE SETTLEMENT

This study did not disclose any significant subsidence problems in the study area. Subsidence is not expected to be a problem in the future and therefore, not a factor in land planning.

In general, the soils within the study area are not compressible under usual loading conditions. A notable exception, however, is the Upper Newport Bay Area. In this region loose and soft soils predominate. The most compressible bay region is Big Canyon and northeasterly of the upper end of the Upper Bay where soft, compressible silts and clay are prevalent.

Placing fill to develop the Upper Bay region would cause excessive settlements unless special precautions were taken.

It is likely that surcharging (placing additional fill temporarily to settle the area prior to construction) would be effective in minimizing areal settlements. However, it is expected that major structures of more than two to three stories would have to be pile-supported in many areas. Detailed geotechnical studies should be made prior to any development of the Upper Newport Bay area.

3.9 FLOODING

Flooding has been projected as the major cost hazard in California for the next thirty years (20). Flooding in the Newport Beach area has not been as severe a problem as in certain other Orange County areas. Probably the potential for greatest damage within the study area lies along the flanks of the Santa Ana River. This river drains an area of over 2400 square miles, extending into Riverside and San Bernardino Counties.

During the floods of 1938, the low-lying basin within the study area adjacent to the Santa Ana River were flooded. With the construction of Prado Dam in 1941, the flooding danger was reduced. However, during the storms of January and February, 1969, the peak discharge of the Santa Ana River reached 19,100 cubic feet per second, closely approaching the design capacity of 20,000 cubic feet per second (14). There was serious erosion of the levees along the downstream portions of the river, which required emergency riprapping and limitations to the flows from Prado Dam. The levees held, but there was considerable pollution of the river and nearby beach areas.

It is our understanding that, even with the presence of Prado Dam and continued upgrading of the flood control facilities, the low-lying areas adjacent to the river could be inundated by an unusually large flow down the Santa Ana River. It is plausible that flows of 2 1/2 to 5 times the design capacity of the river could flow during extreme conditions (D). It is estimated that under the present conditions, flooding could

occur which exceeds the design capacity. Such a flow might occur on the average of once every 30 to 40 years.

A Santa Ana River Basin Study is currently being performed by the Water Resources Investigation Section of the Corps of Engineers. The Corps is studying an array of alternatives to increase the capacity of the Prado Reservoir and/or the Santa Ana River. The target date for the completion of that study is June, 1973.

The main contributaries to Upper Newport Bay are the San Diego Creek and, to a lesser extent, the Santa Ana-Delhi Channel. The peak discharge along San Diego Creek during the 1969 storm was about 6,700 cubic feet per second, and it is estimated that such a flow would occur on the average of once every 50 years (14). Flood damage along this drainage system occurred predominantly within the reaches of the tributaries because the bay is so wide that it easily handled tributary runoff. However, because the water flowed much slower in the bay, the heavy loads of soils which had been eroded from the tributaries were deposited in the recreational areas of the bay.

Flood damages along San Diego Creek included the washing out and flooding of MacArthur Boulevard when water flows exceeded the capacity of debris-plugged culverts at Jamboree Road, and damage to other roads and agriculture. The flooding potential of San Diego Creek is also being studied by the Corps of Engineers and they expect to report on their findings in the fall of 1972.

Unless the studies presently underway by the Corps of Engineers indicates to the contrary, or until corrective measures

are taken, it should be assumed that the low-lying areas around the Santa Ana River and San Diego Creek are subject to flooding.

The flood study areas indicated on Fig. 6 indicate some of the areas where potential flood areas might (but do not necessarily) exist. The areas have been delineated from conversations with personnel with the Corps of Engineers, from mapped general geologic and topographic conditions. They do not always consider specific flood control provisions already in use, and do not include field evaluations.

The flood study areas shown in Fig. 6 indicate areas where it seems reasonable from this limited study that potential major flooding problems might exist. There may be potential major flooding problems in areas not delineated (such as the San Joaquin Hills in the eastern portion of the study area), and there may be areas within the delineated potential flood areas where no such flooding problem exists. A more detailed evaluation is beyond the scope of this study. Potential flood areas should be evaluated carefully from the standpoint of community planning, and, in particular, from the standpoint of siting emergency facilities. The reports being prepared by the Corps of Engineers are expected to evaluate this potential hazard.

4.0 CONTINUED STUDY

As stated in the introductory portion of this report, this study is not complete. Many of the areas where further studies are necessary are listed below. Furthermore, this type of study must be continually updated and refined to be an effective land-planning tool. Recommended updating procedures are also presented below:

I. Seismicity -

A. This study has resulted in identification of potential seismic hazards (ground breakage, shaking and failure) with coarsely defined probabilities and areas of influence. Certain refinement and quantification (within the limits of the state - of - knowledge) are definitely desirable.

Previous soil investigations in the study area have not been designed to obtain data for seismicity evaluation. Therefore, at present, little data necessary for refinement and/or quantification is present. This information requires careful field mapping, special drilling and sampling techniques, sophisticated dynamic laboratory testing and computer analysis which were beyond the scope of the Phase I study.

B. Much additional seismic hazard data can be obtained by using seismic recording instruments to help relate earthquake source and energy to ground

motions and related seismicity and damage (or lack thereof).

To aid in updating and quantifying seismic hazard potentials, a check should be made of the type and locations of existing seismic recording instruments in the study area. It may be desirable to add such instruments if none are present in certain critical areas.

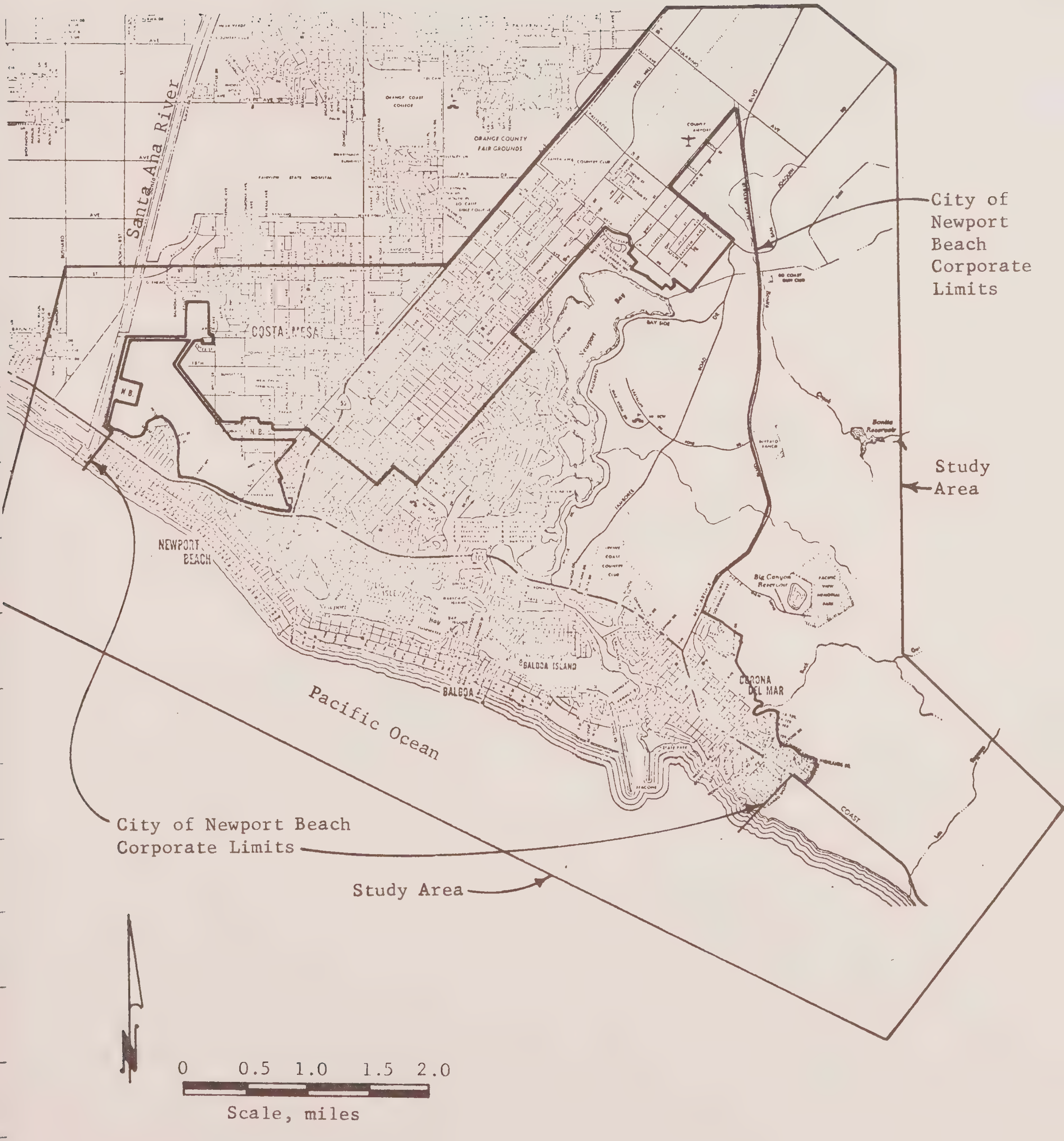
C. This report presents "survivability spectra" based on the maximum credible earthquake event which could occur. It may be desirable to use less severe spectra to design for specific performance of certain strucutres. These criteria should be evaluated with City of Newport Beach personnel. Other spectra criteria can be developed based on other performance requirements as necessary.

D. It may be desirable to develop additional seismic design criteria for certain type structures. Such criteria would probably include recommendations for making existing structures more earthquake resistant.

E. Because the field of soil dynamics is rapidly expanding, the results of the study should be updated on a frequent (semi-annual) basis.

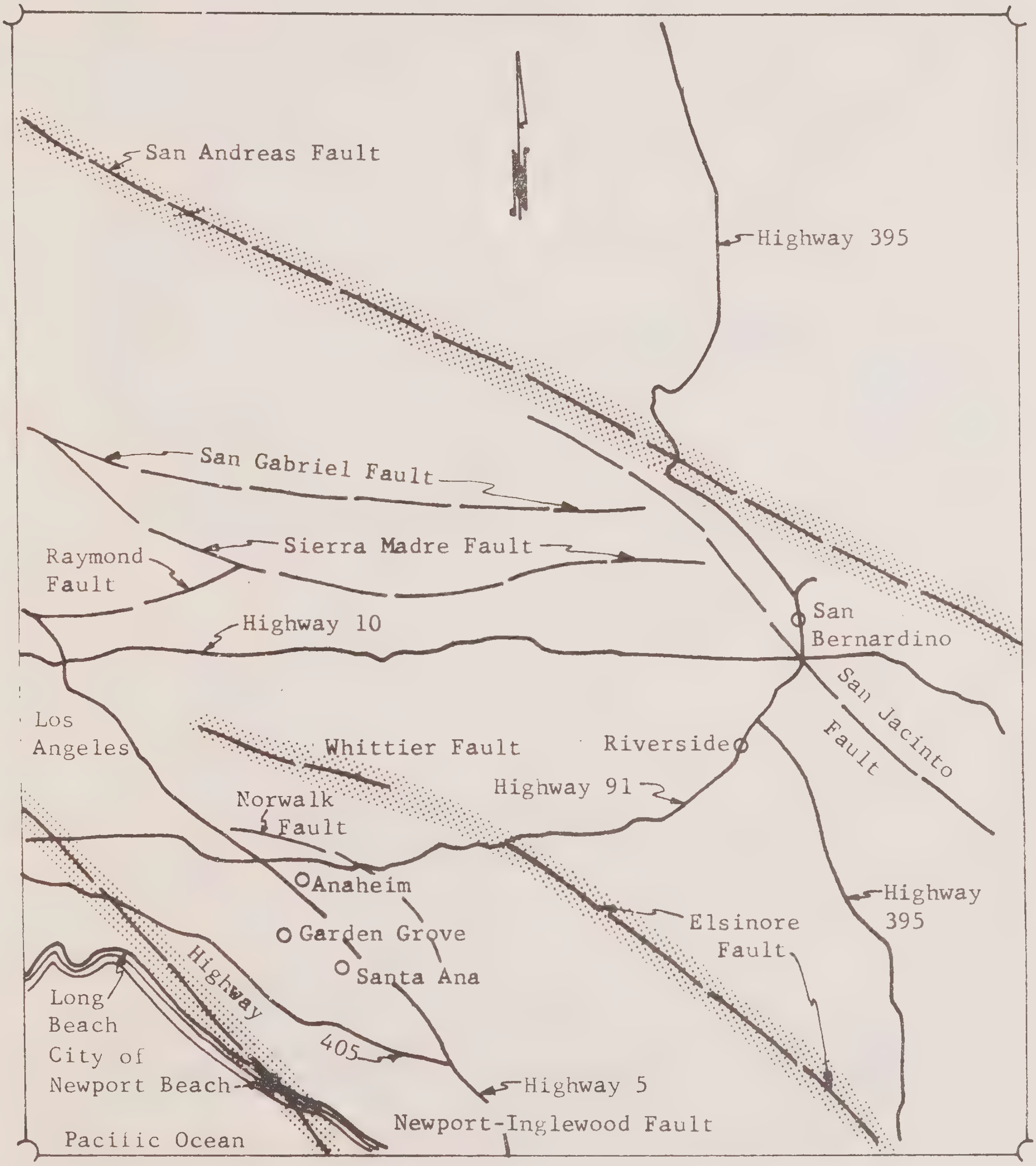
II. Mineral Resource Depletion -

As the pressures on the City necessitate expansion, the City can use or lose potentially valuable resources.



Project Name: Geologic/Seismic Study, City of Newport Beach Job. No. B1671	STUDY AREA	Fig. 1

WOODWARD-McNEILL & ASSOCIATES



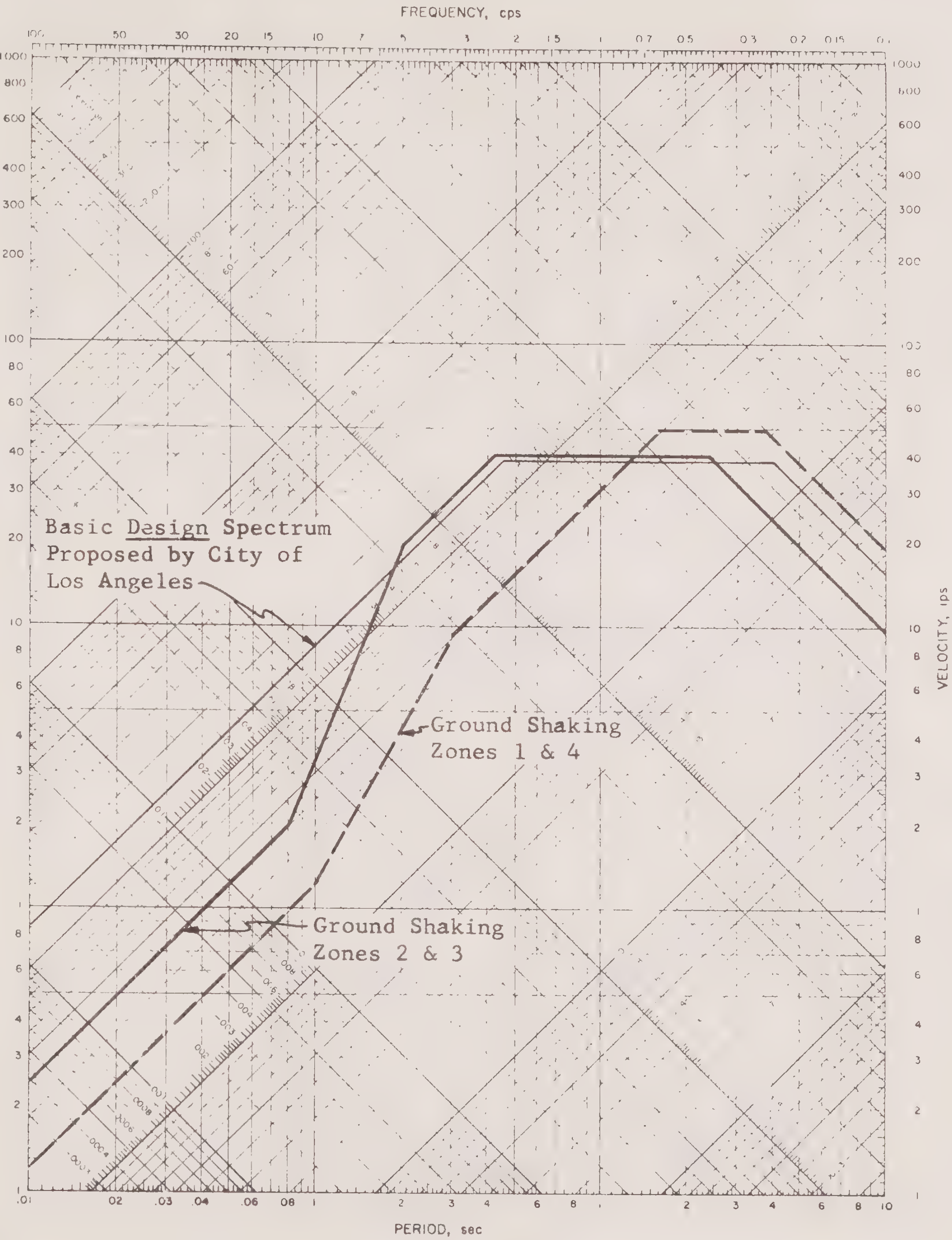
LEGEND:

- Postulated Controlling Capable Fault

0 2 4 6 8 10

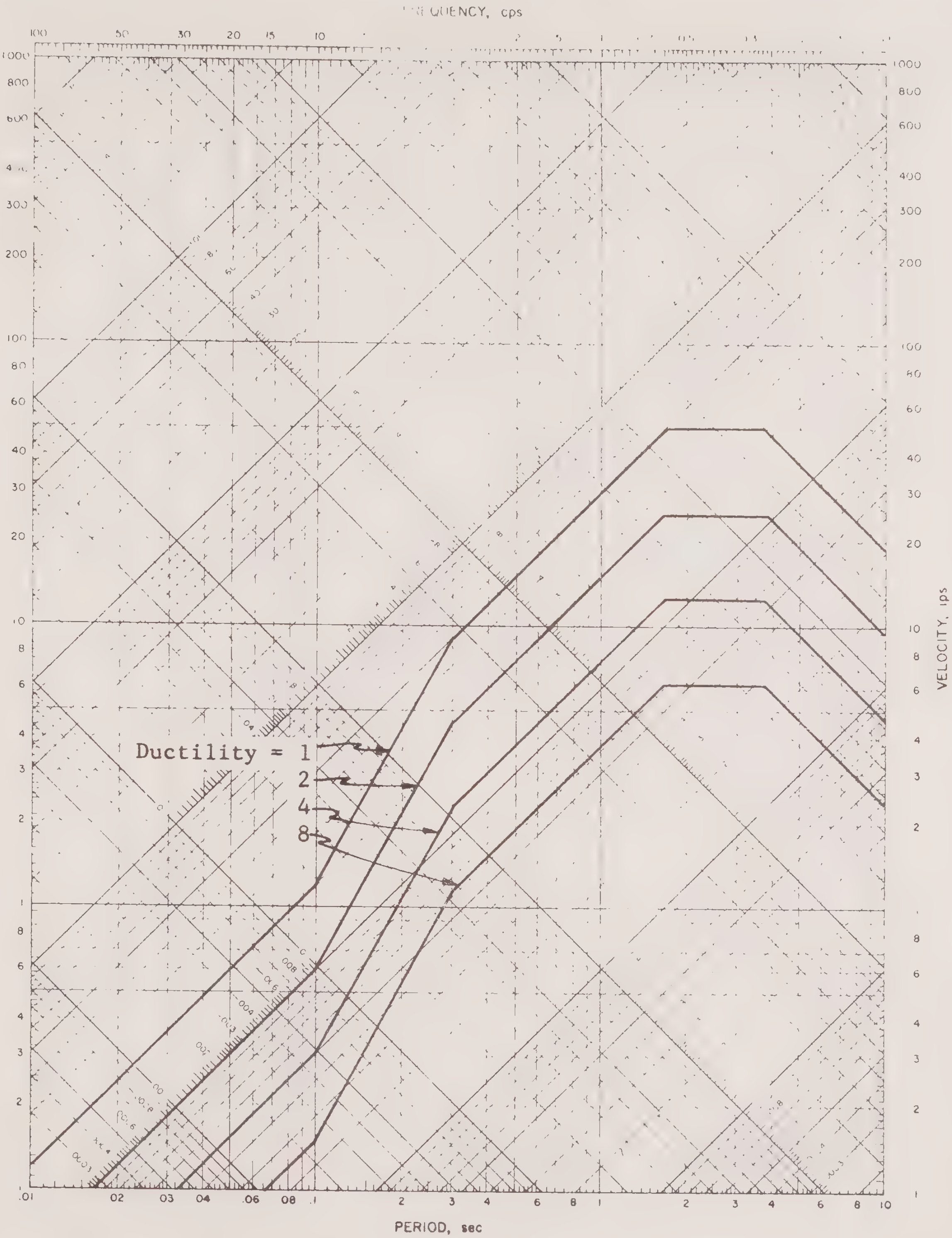
Scale, miles

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B167I	SEISMICITY VICINITY MAP	Fig. 2A



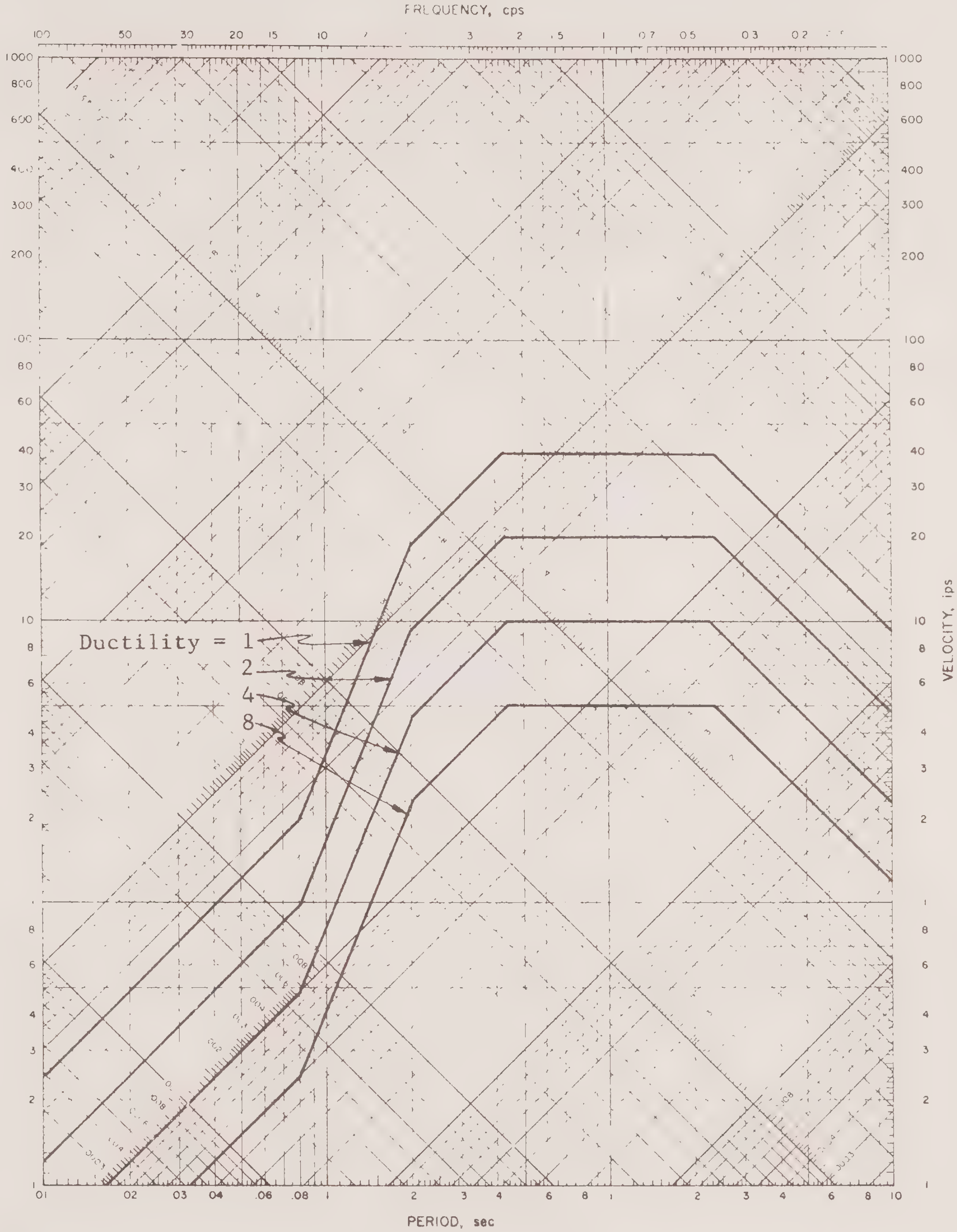
Ductility = 1
Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B1671	SUGGESTED SURVIVABILTY SPECTRA (DESIGN SPECTRA TO BE DETERMINED)	Fig. 2C



Structural Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B1671	SUGGESTED SURVIVABLITY SPECTRA FOR GROUND SHAKING ZONES 1 & 4 (DUCTILITY RATIOS 1, 2, 4, & 8)	Fig. 2D



Structural Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B167I	SUGGESTED SURVIVABILTY SPECTRA FOR GROUND SHAKING ZONES 2 & 3 (DUCTILITY RATIOS 1, 2, 4, & 8)	Fig. 2E

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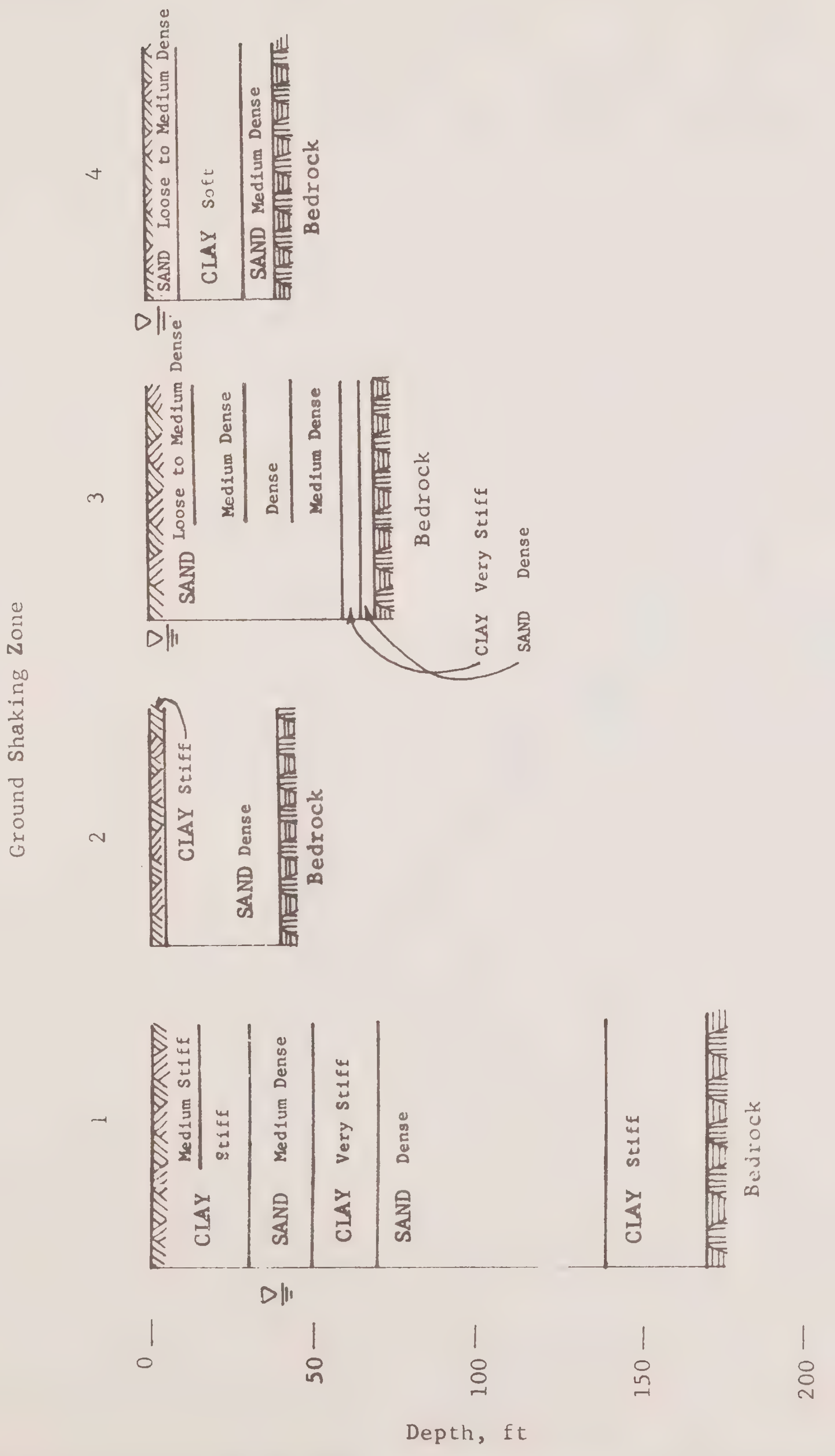
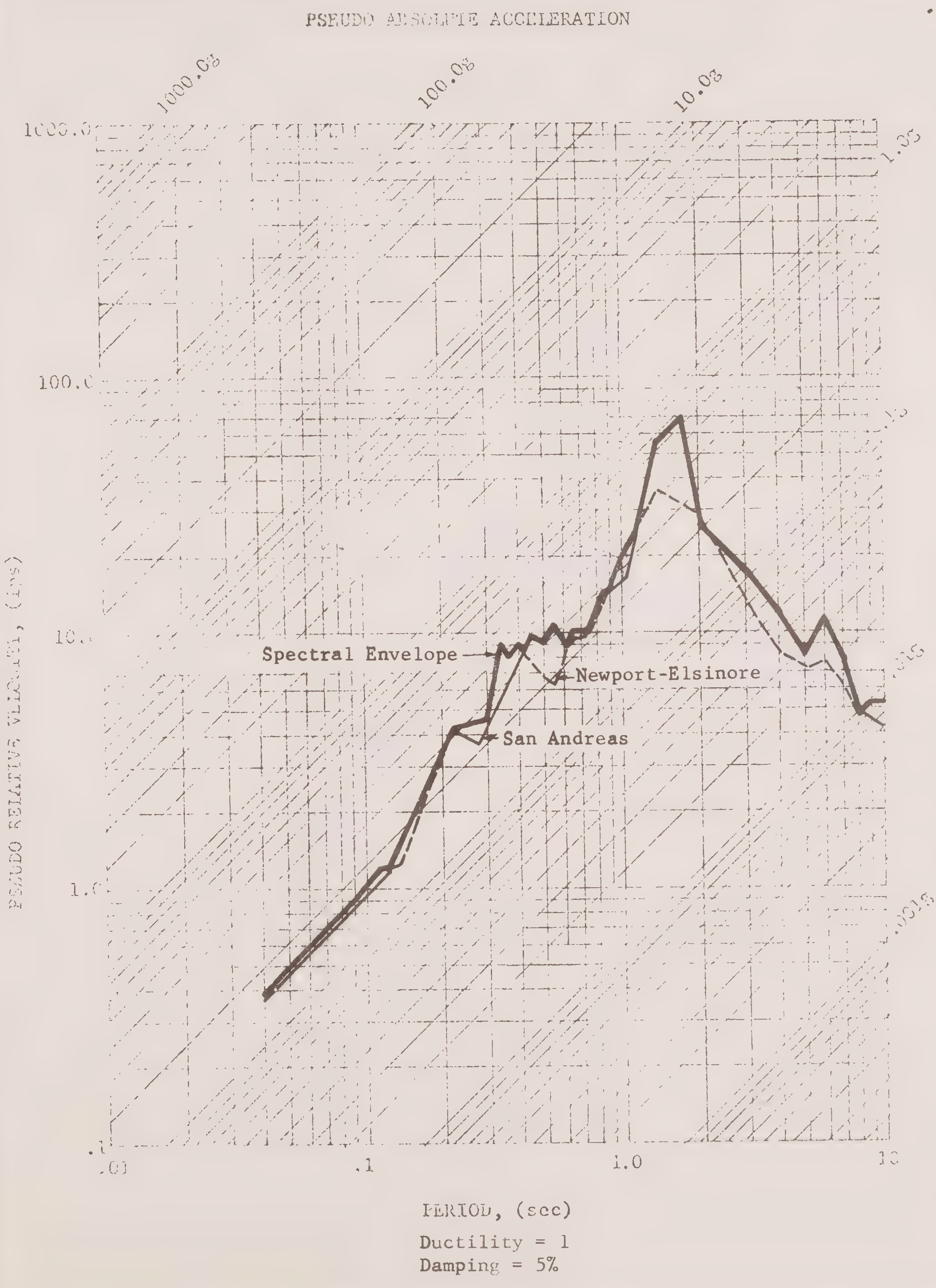
APPENDIX A

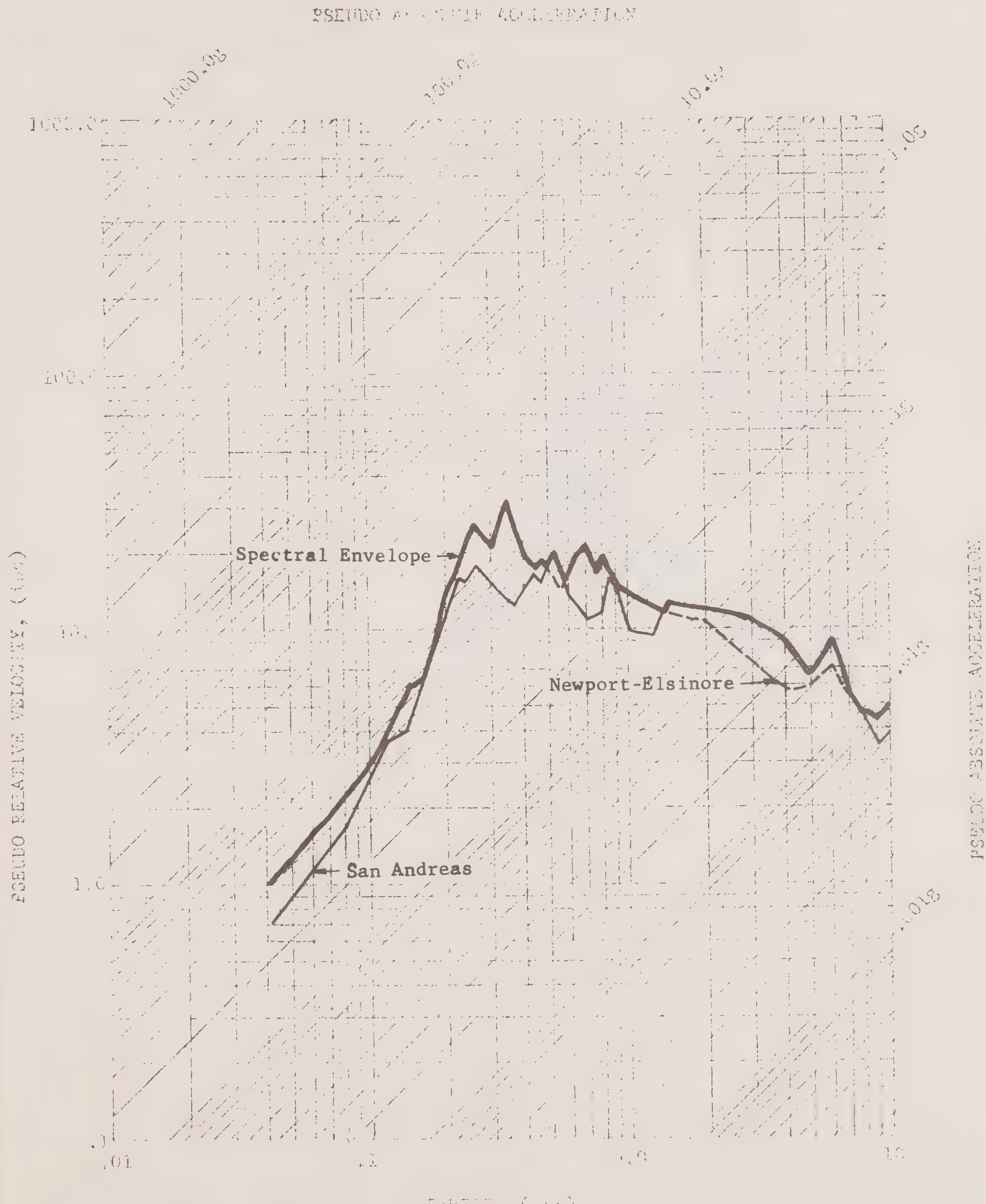
DYNAMIC RESPONSE FIGURES



Project: Geologic/Seismic Study, City of Newport Beach **Job Number**: B1671	GENERALIZED SOIL/GEOLOGIC PROFILES	**Fig.** A-1

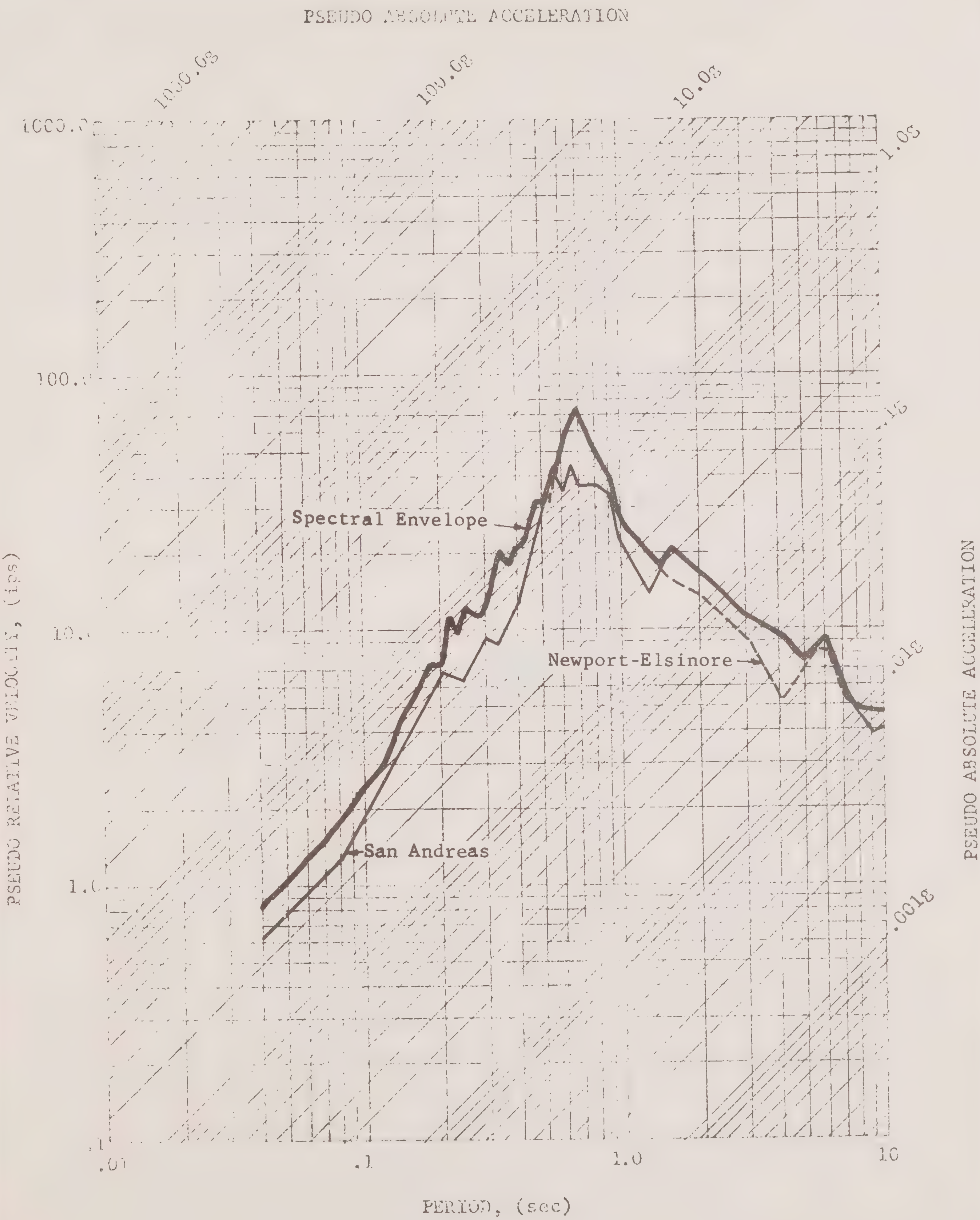


Project Geologic/Seismic Study, City of Newport Beach Job Number B1671	RESPONSE SPECTRA FOR GROUND SHAKING ZONE 1	Fig. A-2



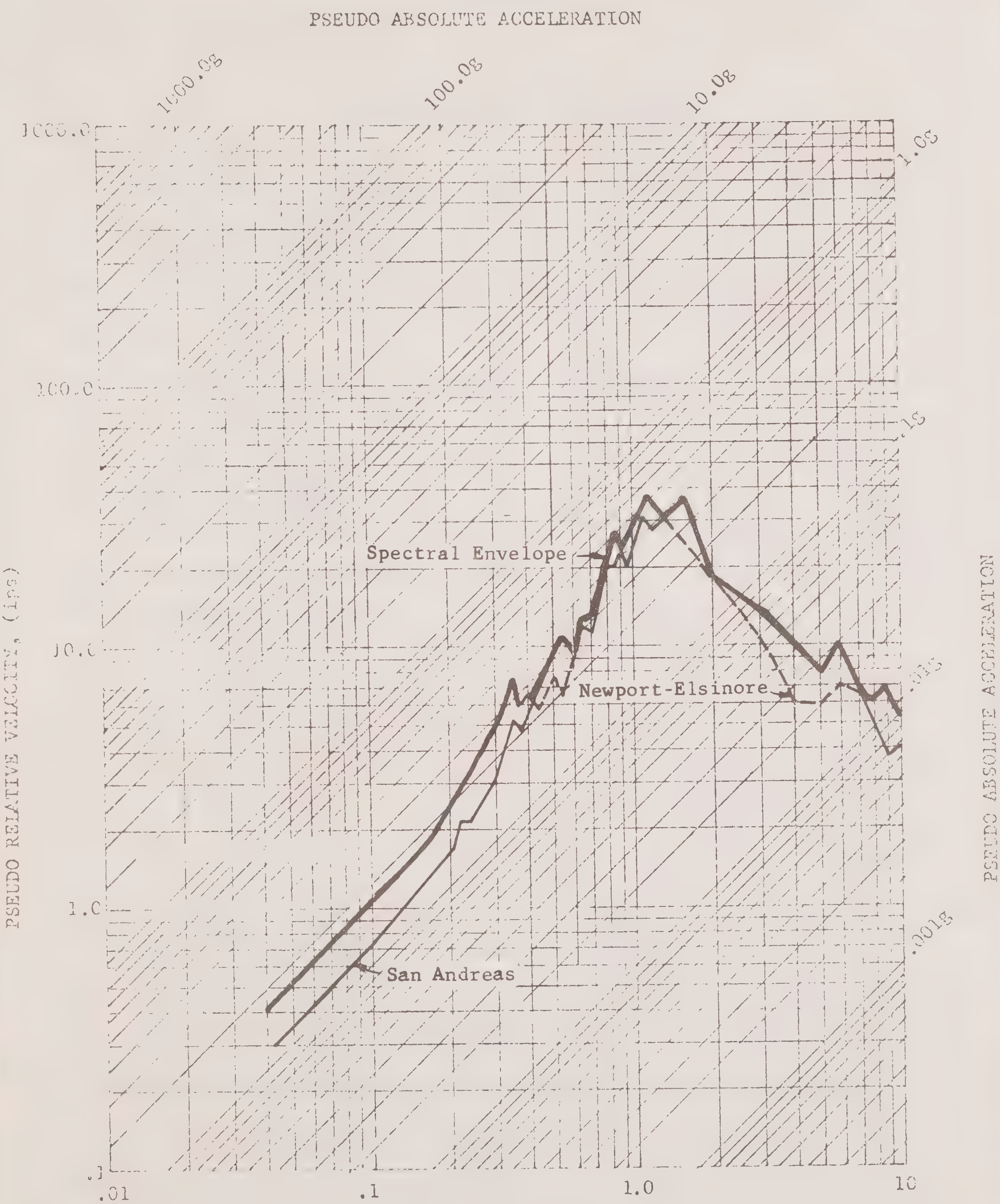
Ductility = 1
Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B1671	RESPONSE SPECTRA FOR GROUND SHAKING, ZONE 2	A- 3



Ductility = 1
Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B1671	REPONSE SPECTRA FOR GROUND SHAKING ZONE 3	Fig. A-4



PERIOD, (sec)
Ductility = 1
Damping = 5%

Project: Geologic/Seismic Study, City of Newport Beach Job Number: B1671	RESPONSE SPECTRA FOR GROUND SHAKING ZONE 4	Fig A-5

APPENDIX B

RESPONSE SPECTRUM METHODS

There are many ways to arrive at response spectra which may be appropriate for design. In this report, the synthesis method has been used. This method has been used because it is site-specific.

Other, but nonspecific, methods were not felt suitable for this study.

Synthesis Method

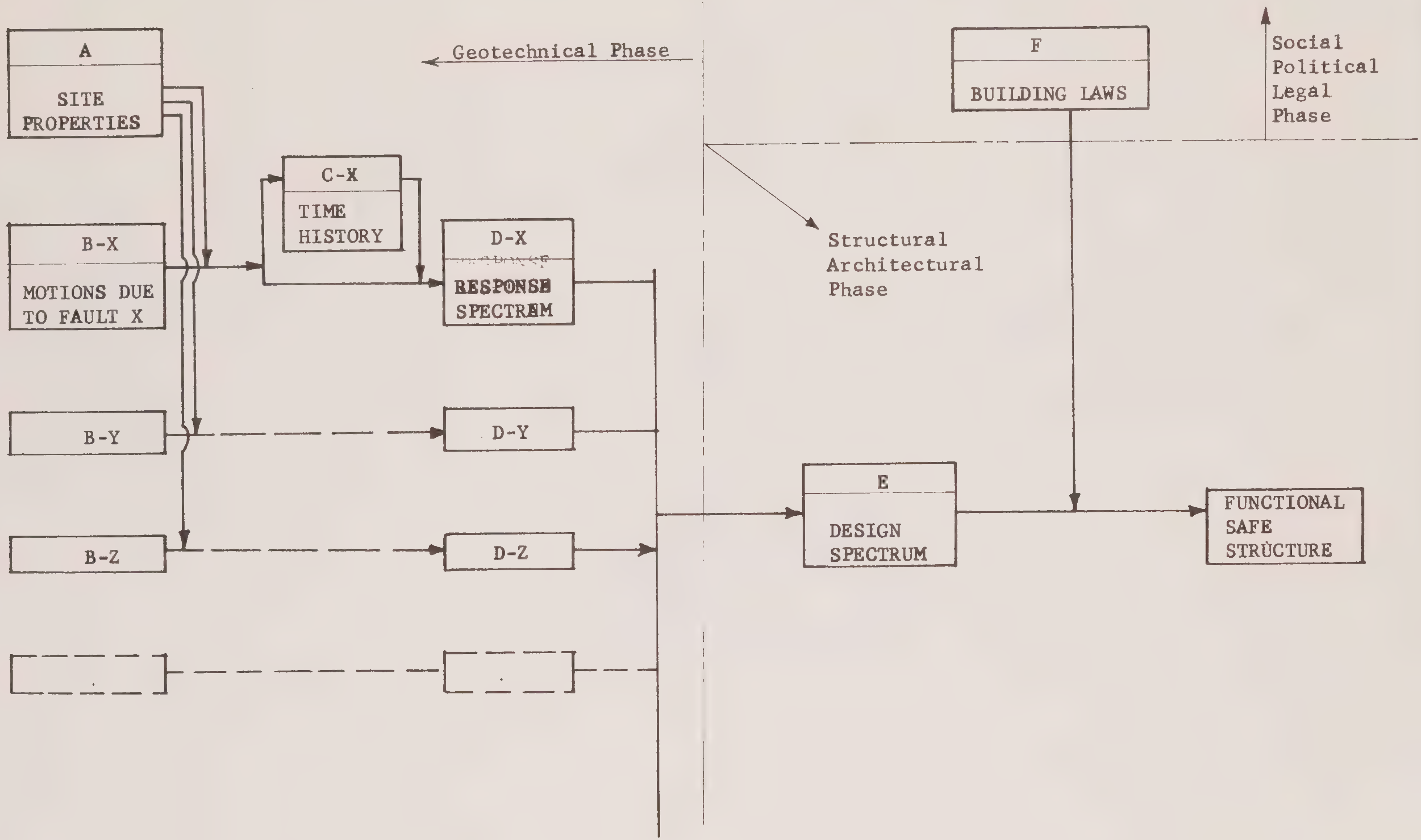
This method requires an evaluation of the causative faults or fault systems, evaluation of the site, and a combining of those two evaluations to arrive at design criteria. Some examples are given in the text.

This method is outlined in Fig. A-1. The site properties are defined, as shown in Chart A, in the Data Package A. The motions due to faults X,Y,Z,...., are estimated from empirical data, as shown in Chart B, in Data Package B-X, B-Y.... These data packages are combined, as shown in Chart C-d, to arrive at the response spectra for an earthquake (fault X, fault Y,...) at the site, in Data Package D-X, D-Y,.... All of the D-Data Packages are combined, Chart E, and enveloped to define, as Data Package E, the Site Design Spectra which represent the range of single degree of freedom structurcl motions at the site for all known causative faults, all structural dampings, every period of motion, and for any structural ductility . The design spectra

are the raw data the Structural Engineer needs to plan his structure.

In addition to the technical raw data, the Structural Engineer must also conform to the local law, usually in the form of a Building Code. As Chart F attempts to show, the Code takes consideration of many factors, including the public's willingness to live in seismically active areas. Unfortunately, that willingness, as well as the attendant obligations and responsibilities, Chart F, are only included by implication, hence any misunderstanding of public acceptance of risk must be litigated.

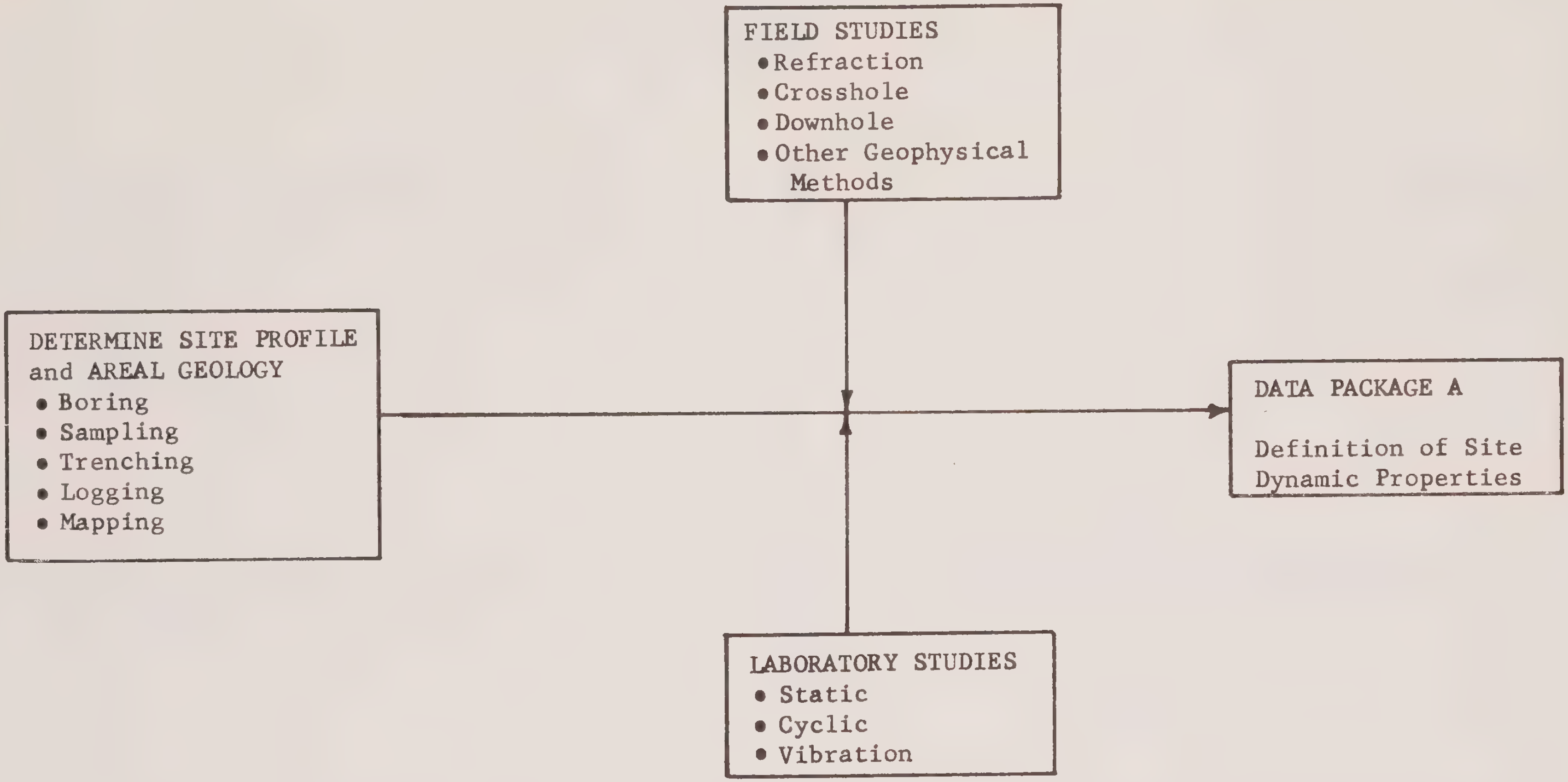
The Structural Engineer, in the context of the Architect's design concepts, uses the spectrum and the code, along with his own knowledge, experience, judgment, and sense of responsibility, Chart G, to design a safe and functional structure.



NOTE: See charts, keyed to letter designations of Data Packages

Project: Geologic/Seismic Study, City of Newport Beach Job No. B167I	FLOW DIAGRAM	Figure B-1

WOODWARD-McNEILL & ASSOCIATES

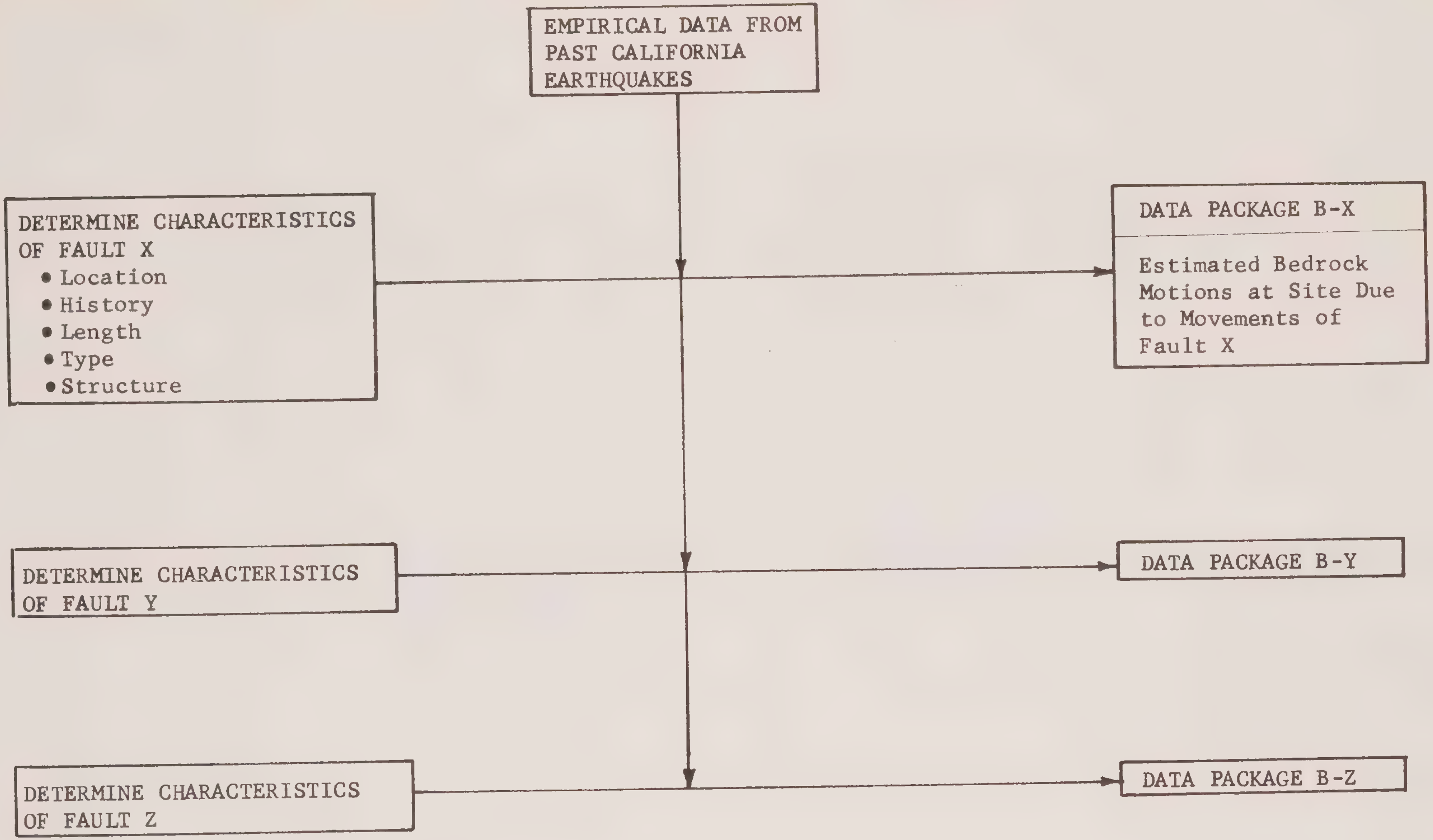


Project: Geologic/Seismic Study, City of Newport Beach

Job No. B1671

CHART A: DEFINE SITE PROPERTIES

WOODWARD-McNEILL & ASSOCIATES

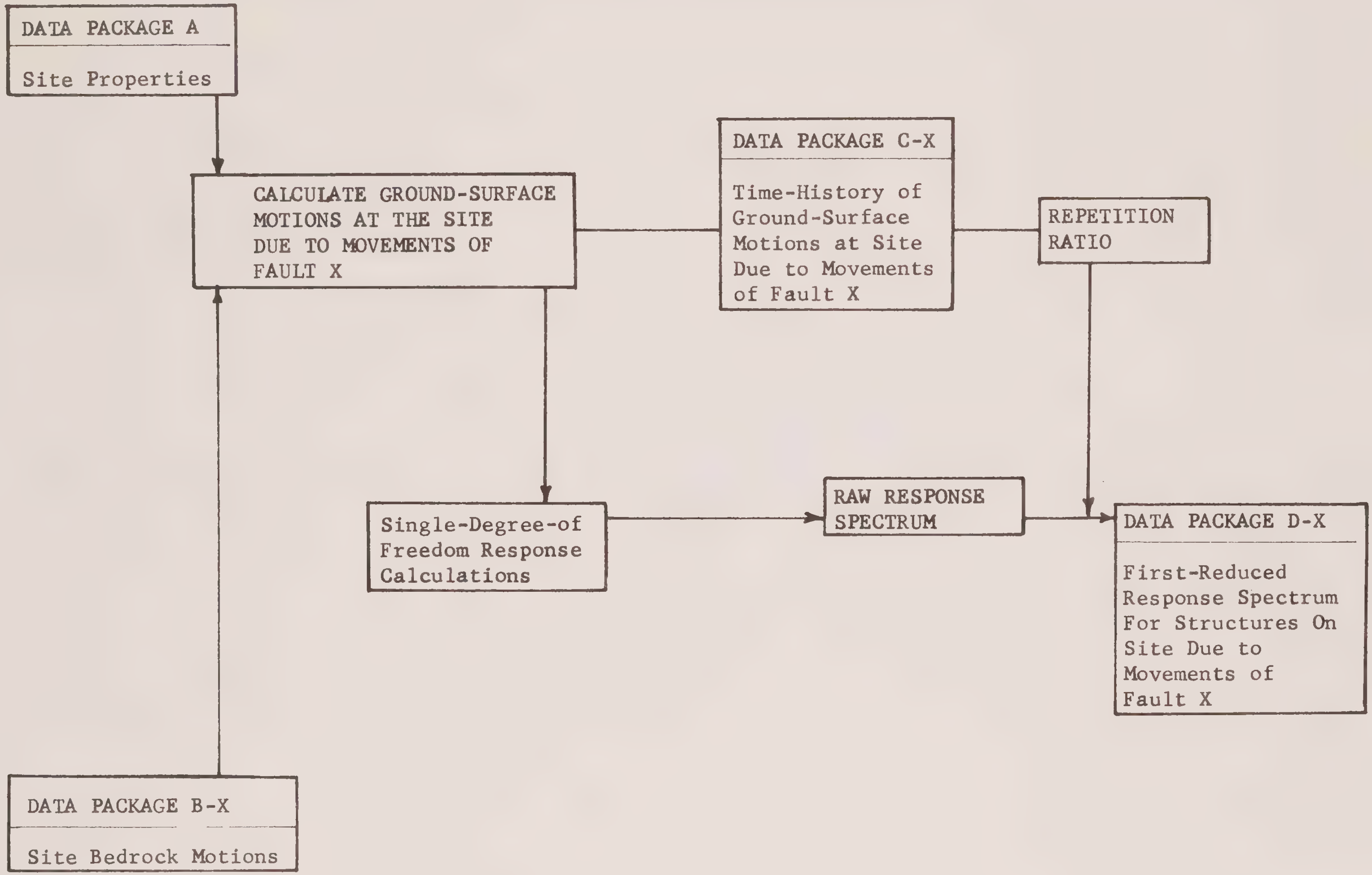


Project: Geologic/Seismic Study, City of Newport Beach

Job No. B167I

CHART B: SITE BEDROCK MOTIONS

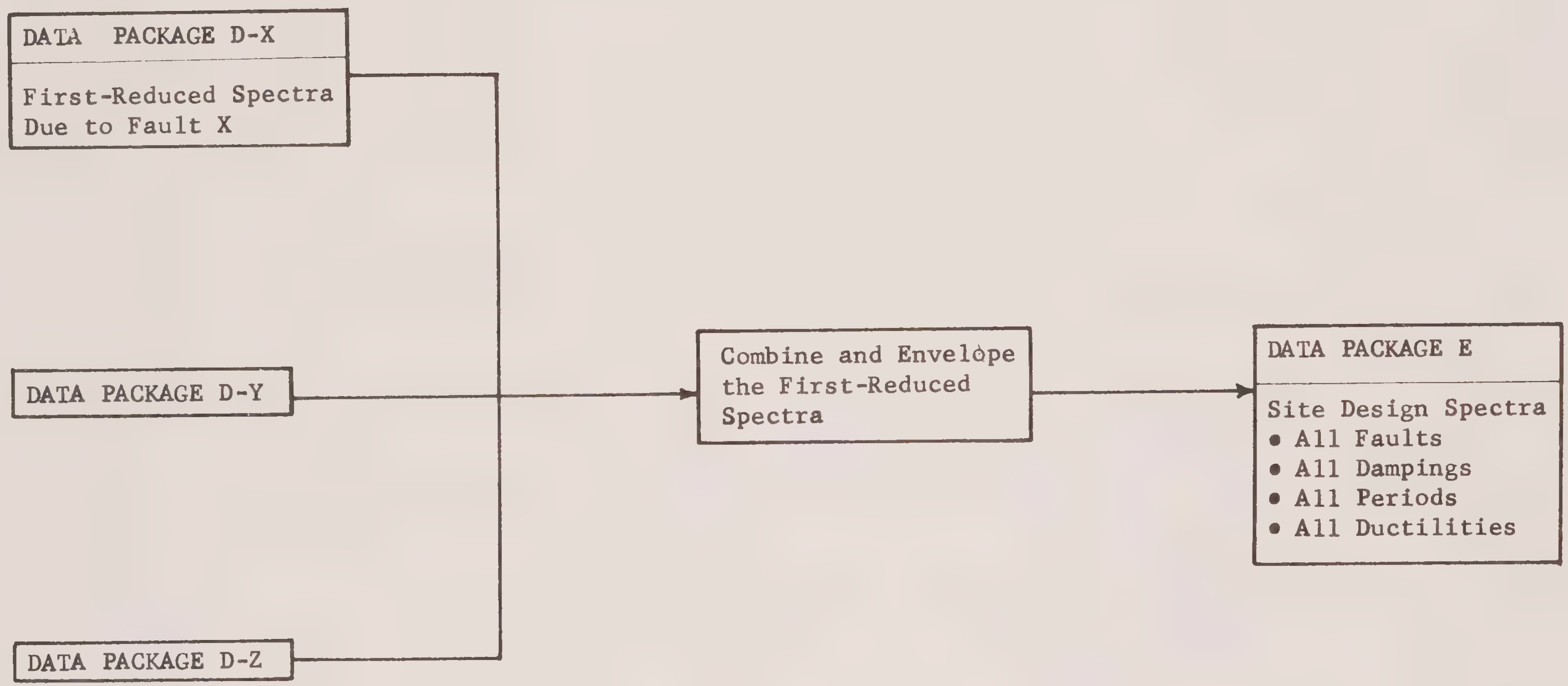
WOODWARD-McNEILL & ASSOCIATES



Project: Geologic/Seismic Study
City of Newport Beach
Job No. B167I

CHART C-D: RESPONSE SPECTRA

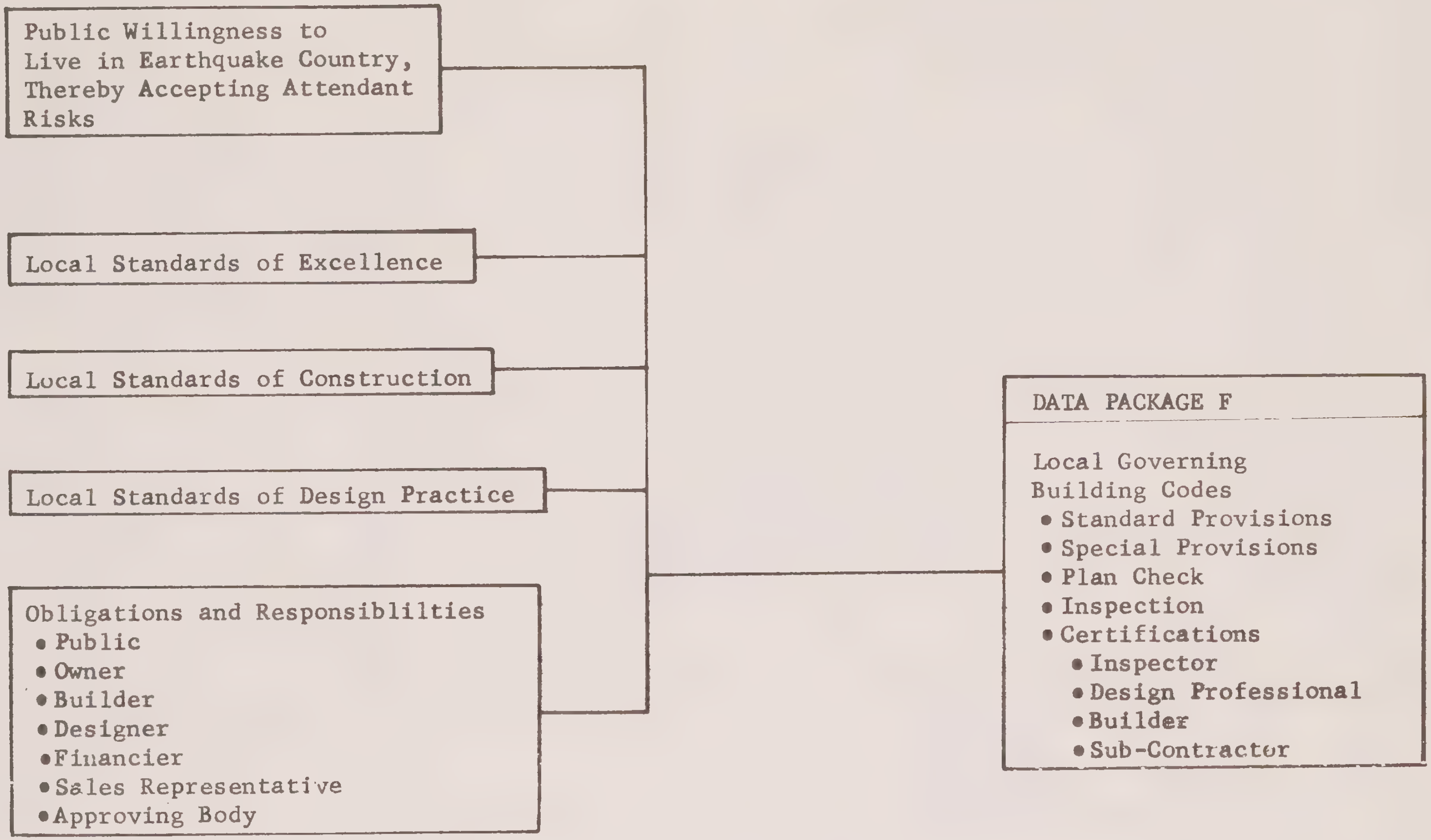
WOODWARD-McNEILL & ASSOCIATES



Project: Geologic/Seismic Study
City of Newport Beach
Job No. B167I

CHART E: DESIGN SPECTRA

WOODWARD-McNEILL & ASSOCIATES



Project: Geologic/Seismic Study
City of Newport Beach
Job No. B167I

CHART F: BUILDING LAWS

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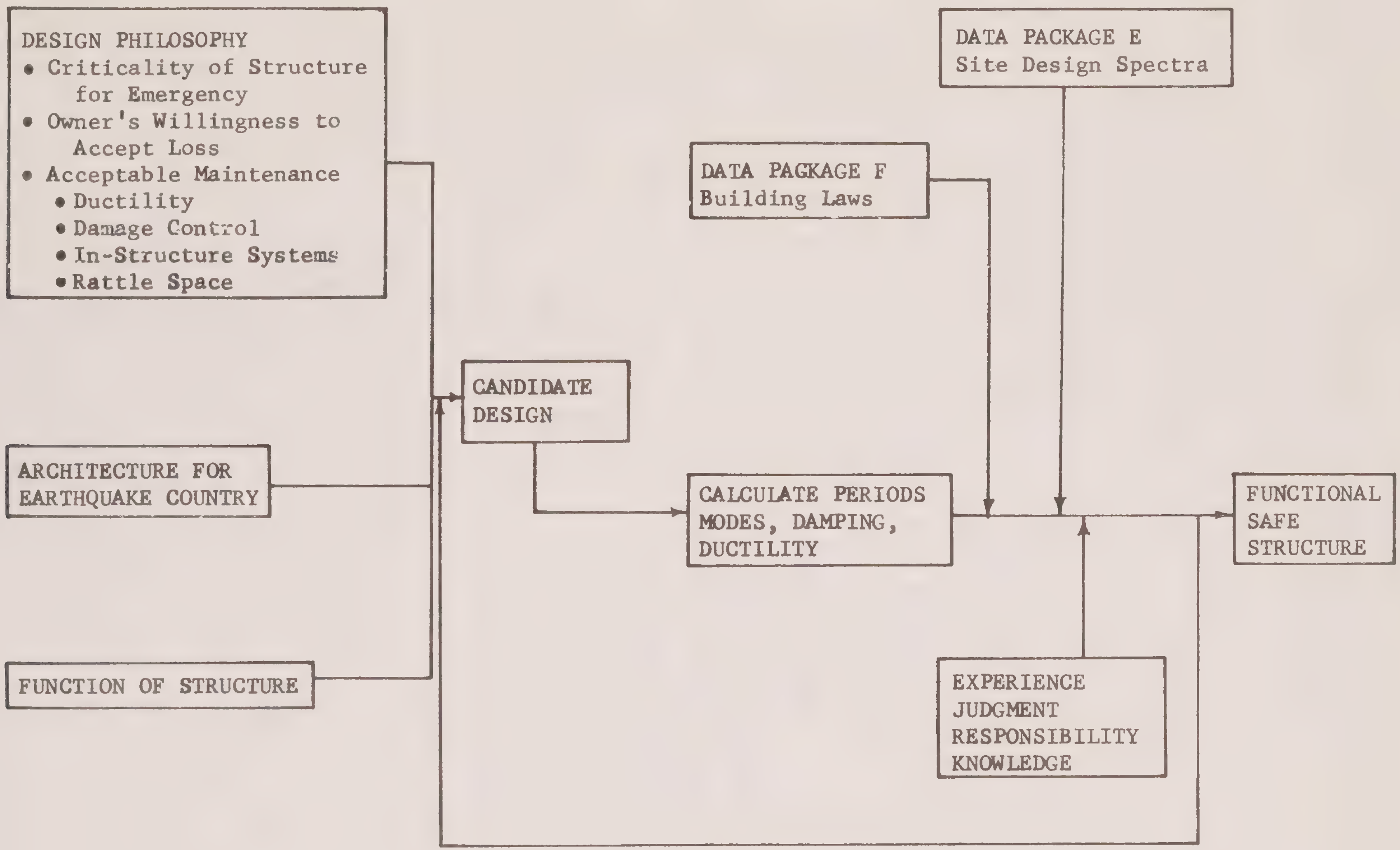

Project: Geologic/Seismic Study
City of Newport Beach
Job No. B167I

CHART G: DESIGN

WOODWARD-McNEILL & ASSOCIATES

APPENDIX C

EARTHQUAKE ASSOCIATED DAMAGE

The contents of this Appendix were adapted from a larger narrative on elementary seismicity prepared by Mr. L.S. Cluff of the affiliated firm of Woodward-Lundgren & Associates.

EARTHQUAKE ASSOCIATED DAMAGE

It is a commonly held misconception that distance from the surface trace of an active fault is the best assurance against earthquake damage. Experience has shown that the intensity of an earthquake is not necessarily highest at the surface trace of the earthquake generating fault. If the structure is not astride an active fault, it matters little whether it is alongside the fault trace or several miles away, because energy reaching the surface will be almost the same at the two points, everything else being equal.

Earthquake damage depends on many variables: earthquake magnitude, epicentral location, depth of focus, duration of shaking, intensity of shaking, near surface soil and geologic conditions, structural type, and design. Damage related to foundation conditions depends upon material density, shear strength, thickness, and water level. Thus, proximity to an active fault should not be given undue weight when deciding where to build; more consideration should be given to ground conditions and structural design.

Earthquake associated damage is usually manifest in four separate forms: (1) fault displacement; (2) strong ground motion

(shaking); (3) ground failure; and (4) tsunamis (seismic sea waves). The first three of these are of importance here and are described below.

Faulting

Faulting, as the movement or fracturing along faults is called, may have horizontal and vertical components of displacement and may vary from a fraction of an inch to many feet. In the California earthquake of April 18, 1906, horizontal offsets along the San Andreas fault averaged from 8 to 15 feet and occurred from just north of San Juan Batista to north of Point Arena, a distance of more than 200 miles.

Fracturing and shearing associated with faulting is often observed in the field to be of a multiple and en echelon character, with several planes of displacement being formed through geologic time (millions of years); thus the term fault zone is a more realistic designation. The exact location and characteristics of a fault zone are of vital concern in estimating the hazard from faulting. Once a fault is formed, it constitutes a plane of weakness that localizes further adjustments. Active faults usually are associated with one or more of the following: a historic record of faulting, the occurrence of earthquakes along their courses, evidence of geologically recent movement (the last few thousand years), and slow fault slippage. A fault should be considered active if it has displaced recent alluvium or other recently formed deposits, whose surface effects have not been modified to an appreciable

extent by erosion, which has earthquakes located in the near vicinity, and whose recurrence of movement is expected.

Some fault zones, such as the San Andreas, are more than a mile wide in places, containing many "fault traces" within the broad zone. One might ask, "What is the relative risk of developing or locating structures within such side active fault zones?" Assigned risk (SR or RSR) need not always be extreme. It depends upon factors such as type of development, intended land use, type of structure, and site location with respect to the active fault traces. The broad fault zones have been formed over long periods of geologic time and in some future geologic time (millions of years) not only may the present fault traces be reactivated, but new traces may be formed. However, if we consider this problem from the standpoint of "engineering design time", (of the order of 100 years, say) the probability of fault movement is much higher along the most recent fault traces that lie within the broad fault zone. In such risk assessments, perhaps weak soil conditions which may arise from crushed rock or gouge in a fault zone would turn out to be more crucial factors than concern over the exact positions of future faulting.

It is often believed that assurance against earthquake damage is directly proportional to the distance from the surface trace of a known active fault or fault zone. There is much evidence that the intensity of an earthquake is not necessarily highest at the surface trace of the earthquake generating fault. If the structure is not astride an active fault trace, so that displacement may shear it in two, it may not be decisive as a

damage factor whether it is alongside the fault trace or several miles away; wave energy reaching the two sites may be comparable. Damage resulting from faulting occurs only where works of man are located astride the fault traces that move. During the 1906 earthquake several buildings of wood-frame, low story construction located near the fault were relatively undamaged. They were also located on stable ground. By contrast, buildings located 10 to 20 miles from the fault, such as in Santa Rosa and San Jose, on relatively less stable ground were almost completely destroyed in the 1906 shock.

Avoidance of damage from fault dislocation can be achieved by recognizing the most active fault traces and either locating structures elsewhere, or allowing for fault movement in the design. This is a significant hazard only in a few localities.

Strong Ground Motion (Shaking)

Damage from strong ground motion (shaking) is caused by the transmission of earthquake vibrations from the ground into the structure. The main variable factors that determine the extent of vibrational damage are: type of ground, earthquake resistant design, quality of materials and construction, and intensity and duration of shaking.

Different kinds of ground respond differently to seismic loading. The relation between soil and basement rock conditions and earthquake shaking is not clearly known. Estimates can be calculated if soil and basement rock properties are known but should be used with caution for risk estimation until more testing under actual earthquake conditions is done. The ground

motion associated with a great earthquake (similar to the 1906 California shock) has never been recorded instrumentally.

Many urban areas are presently located along and near active faults. For example, along the San Andreas fault, throughout its length from Northern to Southern California, along the San Fernando fault in San Fernando Valley, along the Calaveras fault near Pleasanton, along the Hayward fault in the East Bay Cities, along the San Jacinto and Inglewood faults in Los Angeles and Southern California, and the Wasatch fault near Salt Lake City, Utah. Continuing urban growth is bringing about a constant increase in the use of land near active faults that will most likely be associated with substantial earthquakes. Outside the city areas, industrial and utilities development is frequently considered for sites close to active faults. A case which gave rise to strong public controversy is the Bodega Head site north of San Francisco considered a few years ago for a nuclear power reactor.

In these circumstances, the following question is becoming increasingly frequent: "In what ways, if any, does the strong ground motion differ near the fault from the ground motion some distance away?" No strong motion records were obtained of the large 1960 Chilean earthquake, nor in Alaska from the 1964 shock. A widely used strong motion record in engineering design is the El Centro record. It, however, was obtained about 6 miles from the Imperial Valley fault along which displacements were observed in the 1940 earthquake, M6.9. In 1966, an array of strong motion instruments was operational across the San Andreas fault near

Cholame. These instruments recorded the earth movements at the time of June 27, 1966 Parkfield earthquakes. A record of ground acceleration was obtained within the fault zone about 200 feet from a fault trace that contained a slippage crack that appeared across Highway 46 where it intersects the San Andreas fault zone. These records are the closest to an earthquake source (active fault) yet obtained. (The records showed that the vertical and horizontal motions of the ground differed considerably in their frequency content and structure.) There was a large ground motion (which amounted to a displacement of 10 inches) perpendicular to the fault trace. The maximum horizontal ground acceleration was one-half the acceleration of gravity (0.5g), i.e., about 16 feet/sec^2. The duration of the strong ground motion was extremely short, lasting only about 1 second.

Although the records give valuable information, it is unclear whether the effects mentioned above could be scaled upwards for a large earthquake. The Parkfield main shock had a magnitude of 5.6 and the length of fault rupture observed was somewhat less than 20 miles. Very little damage was reported along the fault zone, even though the short duration peak acceleration was surprisingly quite high. It is not clear whether a much larger magnitude earthquake might produce significantly greater accelerations near the fault; a longer interval of ground shaking (duration) is, however, quite likely.

Because we lack direct observations, forecasts of ground motion must be largely based on extrapolation from experiments in the laboratory, from visual observations of past earthquakes,

and upon suggestions from theoretical models. Certain likely properties of the ground motion near a fault can be stated for risk estimation, subject to the necessary cuation implied by the above statement of our lack of current observational information.

Damage from Ground Failure

Damage from ground failure may occur in several different forms; landsliding, liquefaction, and settlement.

If the proper geological conditions exist on the ocean floor, subaqueous landslides or turbidity currents may be generated of sufficient force to affect offshore and onshore structures. In 1929, an earthquake in the North Atlantic triggered a high-velocity, high-density turbidity current that is believed to have led to the shearing of 11 Trans-Atlantic communication cables. The sea floor over which this flow occurred had no more than a 2% to 5% slope. Numerous subaqueous landslides occurred during the 1964 Alaska earthquake causing extensive damage to nearby areas, especially from large water waves that were generated by the landsliding. Saturated granular layers were generated by the landsliding. Saturated granular layers located at shallow depth below the surface may be sucsceptible to liquefaction during an earthquake. This phenomenon has frequently been observed in the past, notably in Niigata, Japan, in 1964 and Chile in 1960.

In general, the greater the depth and relative density of a submerger sand layer, the less is the danger of liquefactioo. Shallow loose saturated sands appear to be most liquefiable, deep dense sands least liquefiable.

APPENDIX D

GLOSSARY OF GEOTECHNICAL TERMS

The definitions presented are related to usage in this report.

Active Fault: A geologic fault on which there has occurred significance subsurface earthquake activity, or any surface ground breakage, within post-Pleistocene time (generally taken as during the last 5 to 20,000 years).

Aftershocks: A sequence of smaller shocks following an earthquake.

Alluvium: Geologically recent surficial deposits, which have not undergone significant cementation or consolidation. Typically sands, gravels, silts, or clays.

Anticlinal Structure: An elongated fold in a rock mass where the sides or limbs slope downward away from the crest.

Basic Design Spectrum: Form of response spectrum (see below) proposed to be included in code changes relative to earthquake resistant design for the City of Los Angeles.

Bedrock: The solid, undisturbed rock in place either at the surface or beneath superficial deposits of soil.

Causative Fault: A fault which is considered capable of earthquake activity which would effect the study area.

Collapible Soil: Loosely packed, fine-grained materials which are sometimes cemented with soluble material and which collapse when wetted.

Controlling Faults: The most important causative faults (see above) for the study area.

Critical Damping: The minimum level of damping at which a system will return to its neutral position without oscillation.

Dip-Slip: Type of fault movement in which the principal relative motion is in the vertical sense rather than the horizontal sense.

Ductility: The measure of the ability of a plastic body to undergo large deformations without fracture.

Dynamic Deflection: Deflection under dynamic (seismic) loading.

Expansive soil: A soil which has the capability of large volume changes reflecting increase or decrease in moisture content.

Fanglomerate: A sedimentary deposit resulting from rapid deposition of eroded materials in alluvial fans.

Fault: A plane of breakage in rock or soil, along which significant (greater than an inch or so) offsetting of the two sides of the plan has taken place, due to tectonic forces.

Fault Scarp: A relatively steep, straight slope which is caused by the movement along a fault.

Fault Trace: The line of intersection of a fault surface with the earth's surface.

Ground Breakage: Lateral or vertical displacements occurring in the top several feet of soil or rock and extending to a fault plane at depth, due to movement on that fault plane.

Ground Lurching: Surface cracking or distortion due to motions of the ground during an earthquake. Not necessarily directly connected to a fault plane.

Ground Shaking: Motions of the soil or rock during an earthquake. May or may not result in breakage, lurching or other phenomena.

Liquefaction: The sudden large decrease of the shearing resistance of a cohesionless soil resulting from high water pressure between soil grains.

Offset: The horizontal distance between two parts of a disrupted bed previously joined.

Response Spectrum: A graphical tool of structural dynamic analysis relating the response of a structure(in the forms of deflections, velocities and accelerations) to ground motions (including those resulting from an earthquake).

Reverse Fault: A steeply inclined fault, on which motion is primarily in a vertical sense, with the "over hanging" side moving upward.

Right or Left Lateral Fault: A fault on which relative motion is primarily in a horizontal sense, with the motion of the opposite side of the fault, when viewed from one side, to either the right or left, respectively.

Seismicity: Related to earthquakes.

Shoreline Regression: Loss of beach width.

Slope Stability: The ability of a slope of soil or rock material to resist moving downhill.

Soil or Structural Damping: The (velocity) diminution of the vibrational responses of a soil/bedrock mass or a structure, expressed as a percentage of critical damping (see above).

Soil Stiffness: Resistance of a soil mass to deformation under loading.

Subsidiary Faults: Auxiliary cracks either branching obliquely or lying subparallel to the main line of rupture.

Subsidence: A local mass movement of earth material in which surface material is displaced vertically downward/ areal settlements with little or no horizontal component.

Survivability Spectrum: The site-specific response spectrums (see above) associated with the ground motions resulting from the maximum credible earthquakes occurring on controlling faults (see above).

Tectonic Stress: Stress caused by rock structures resulting from the deformation of the earth's crust.

Tsunami: Sea wave generated by a submarine earthquake, landslide or volcanic action.

Working Stress: A stress below the yield or ultimate stress at which a structure is expected to perform satisfactorily on a routine basis.

APPENDIX E

STRONGER LOCAL SHOCKS ALONG THE NEWPORT-INGLEWOOD ZONE, MARCH 1933 THROUGH 1970

(Source: Seismological Notes, Bull. Seismol. Soc. America)

Date	Locality Data	Intensity (Modified Mercalli)	Magnitude
1933 10/2	Signal Hill (Long Beach Los Angeles, Compton, Bell)	VI	5.4
1939 12/27	Long Beach (Huntington Park, and Long Beach damaged)	VI	4.5
1941 10/21	Gardena (damage in west Dominguez oil field)	VII	4.9
1941 10/22			3.8
1944 6/18	Dominguez Hills 16:10:33 PST	VI	4.5
1944 6/18	Dominguez Hills 19:06:07 PST	"sharp jarring"	4.4
1949 12/26	Inglewood and West-chester (El Segundo, Torrance, Hawthorne, Hollywood)	"sharp"	?
1961 10/4	Orange County		3.7
1961 10/20	Orange County 4 larger shocks out of 8 tremors		3.9
1961 10/20	"		4.6
1961 10/20	"		4.2
1961 10/20	"		4.2
1961 11/20	Orange County (with 3 aftershocks)		4.0

Date	Locality Data	Intensity (Modified Mercalli)	Magnitude
1966 10/2	Felt over SW L. A. County, felt sharply in Los Angeles		3.8
1967 5/12	Between South Gate and Lynwood, felt in Pasadena		2.9
1969 10/27	Laguna Beach (offshore)		4.3
1970 9/14	Felt in West Los Angeles area		3.0
1970	Felt in West Los Angeles area		4.2
1970 9/23	Felt in Inglewood-Torrance area		3.3
1970 9/23	Felt in Inglewood-Torrance area		3.2
1970 9/23	Felt in Inglewood-Torrance area		3.2

APPENDIX F

LISTING OF RECORDED STRONGER EARTHQUAKES WHICH MAY HAVE OCCURRED ON THE NEWPORT-INGLEWOOD FAULT ZONE UP TO 1933

Date	Locality Data	Intensity Rossi-Forel Scale
1769 7/28	Los Angeles region	VI?; X?
1812 12/8	Southern California coast	(M.M. scale) VIII-IX
1827 9/23	Los Angeles	?
*1855 7/10	Los Angeles county (offshore?)	VIII
*1860 1/26-27	Los Angeles, night	"severe shock"
1860 3/26	Los Angeles	?
1862 6/7	Los Angeles	?
1864 7/18	Los Angeles	?
1878 6/11-12	Los Angeles 4 shocks	III, V, III, I
1878 Late summer	Inglewood	(M.M. scale) VIII
1879 8/10	San Fernando, "Tidal wave at Santa Monica"	IV?; V?
1880 11/21	Los Angeles and south and east of Los Angeles 3 shocks	?
1880 12/19	Los Angeles and San Diego	V
1885 9/13	Southern California, Los Angeles to San Diego to San Bernardino	IV

Date	Locality Data	Intensity Rossi-Forel Scale
1893 5/18	Southern California coast region "most severe southeast of Ventura"	VII?
1894 7/29	Southern California, 2 shocks at Santa Monica - "last heaviest ever felt there"	VII
1906 4/19	San Pedro	?
1906 4/20	Santa Monica	?
1917 2/13	Los Angeles and southwest of business district	V to VI
1917 6/9	Los Angeles, noticed in southwest portion of city	"felt"
1917 6/24	Los Angeles (12 p.m.)	III to IV
1917 6/25	Los Angeles (8:15 p.m.)	III to IV
1917 6/25	Los Angeles (8:24 p.m.) southern portion of city	IV to V
1917 6/26	Los Angeles (3:51 a.m.) trembling motion	III
1917 6/26	Los Angeles strongest in southern part of city (1:15 p.m., 1:20 p.m., 1:30 p.m.)	V to VI
1917 6/28	Los Angeles rumbling	IV
1917 6/29	Los Angeles trembling	III to IV
1917 6/30	Los Angeles southern part	IV

Date	Locality Data	Intensity Rossi-Forel Scale
1917 7/15	Los Angeles	"slight"
1917 7/17	Los Angeles, 3 shocks, swaying	IV
1917 8/3	Los Angeles rocking motion	III
1917 11/23	Los Angeles, southwestern part of city	II to III
1918 3/6	Los Angeles region most severe in Venice and Santa Monica	V to VI
1918 3/8	Venice and Ocean Park bumping and rumblings	IV to V
1918 11/19	Santa Monica Bay region, Venice, Long Beach, Pomona	VI to VII
1919 2/9?	San Pedro (?) may be wrong	?
1920 2/22	Sawtelle (west Los Angeles)	VI
1920 2/23	Sawtelle	"felt by several"
1920 3/3	El Segundo, Manhattan Beach Redondo Beach	III to IV
1920 3/16	Sawtelle (5 shocks)	III
1920 3/24	Sawtelle (2 shocks)	"felt by several"
1920 4/17	Sawtelle	"felt by several"
1920 4/22	Sawtelle, northwest to southeast motion	"felt by several"
1920 4/30	Sawtelle	"light"
1920 5/4	Sawtelle	"light"
1920 5/18	Santa Monica, abrupt bumping, southwest to northeast motion	III

Date	Locality Data	Intensity Rossi-Forel Scale
1920 5/21	Sawtelle	III
1920 6/18	Los Angeles region (2:08 a.m.) possible origin at sea in San Pedro channel	"Seismograms show about VIII"
1920 6/18 or 19	Inglewood (10:30 a.m.)	"light"
1920 6/21	Inglewood early afternoon (fore-shocks)	"light shocks"
1920 6/21	"Inglewood Earthquake" (6:48 p.m.)	VIII to IX
1920 6/22	Inglewood (2:30 a.m.)	"2 strong shocks"
1920 6/22	near Inglewood also Torrance (4:00 a.m.)	"strong"
1920 6/22	Inglewood (5:00 a.m.)	?
1920 6/22	Inglewood (12:35 p.m.)	V
1920 6/22	Inglewood (9:09 p.m.)	"sharp"
1920 6/23	Inglewood (4:06 a.m.)	"sharp"
1920 6/23	Inglewood (6:51 a.m., 2:10 p.m., 2:24 p.m.)	"all very light"
1920 6/24	Inglewood	"light"
1920 6/29	Inglewood	V
1920 6/29	Los Angeles (possibly previous shock)	III
1920 7/10	Los Angeles	III to IV
1920 7/10	Series of extremely localized shocks northwest of Los Angeles business district	II to VII
1920 12/27	Los Angeles and Inglewood (2 shocks)	III
1923 12/6	Southern Los Angeles County from coast ast to Whittier	?

Date	Locality Data	Intensity Rossi-Forel Scale
1925 3/2	Long Beach	III
1925 5/1	Southern California coast Long Beach	IV
1926 12/29	Redondo Beach north northwest to south southeast, report in Los Angeles, too	IV
1927 1/29	Sawtelle, felt as far as Riverside, origin near Sawtelle	IV or V
1927 2/6	VI in Sawtelle V to VI in southwest Los Angeles sharp in Santa Monica	VI
1927 4/15	Los Angeles Region strongest at beaches southwest of Los Angeles	rattling of buildings
1927 8/4	Los Angeles and neighboring towns "reported that the shock brought in an oil well which was being drilled near Long Beach	?
1927 10/8	Origin east of Compton	VI
1927 12/10	Inglewood "source same as that of 1920 shocks"	?
1927 12/15	Near Torrance. Origin southeast of 12/10 earthquake	?
1928 1/7	Santa Monica, shook crockery, no damage	II-III
1928 12/31	Near Torrance, reported from Santa Monica, Long Beach, and other beach towns to Los Angeles	

Date	Locality Data	Intensity Rossi-Forel Scale
1930 8/30	Near Santa Monica, at Los Angeles and towns surrounding Santa Monica Bay, 11,500 square miles affected	VII-VIII
1930 8/31	Six aftershocks of 8/30 shock	
1930 9/30	Culver City	"fairly strong"
1931 7/13	Huntington Beach	"slight"
1931 7/27	Huntington Beach	"feeble
1931 8/13	3 miles east of Torrance near Lomita	"feeble"
1931 8/14	Torrance (same as above)	
1931 8/30	Huntington Beach, center in San Pedro Channel according to Pasadena	"feeble"
1931 11/1	Bell	"feeble"
1931 11/3	Los Angeles region, T. 4 S., R. 14 W., near Hawthorne, 3 miles east of Torrance Compton, Inglewood, Redondo Beach, South Gate	IV-V
1932 1/25	Wilmington 118° 17' W, 33° 54' N	"light"
1932 1/31	Hynes, Long Beach, Wilmington, and near Torrance 33° 53' N, 118° 19' W	"weak"
1932 2/10	Wilmington, 33° 54'N, 118° 17' W	"slight"
1932 3/21	Los Angeles region, 33°54' N., 118° 17' W, Lawndale, Inglewood, Los Angeles, Manhattan Beach	IV

Date	Locality Data	Intensity Rossi-Forel Scale
1932 5/15	Near Torrance, 33° 48' N, 118° 14' W	
1932 7/30	Bell, and Los Angeles 33° 55' N, 118° 10' W	"weak"
1932 10/21	Los Angeles and vicinity, Hollywood, Lennox, Long Beach, San Pedro, 33.7° N, 118.3° W	IV
1932 11/29	Huntington Park	III
1932 12/6	Huntington Beach (five miles north of) Blast?	IV
1932 12/22	Huntington Beach	"slight"
1933 3/9	Huntington Beach	IV

APPENDIX #G

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